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Effect of Boron Fertilization and Boron Enriched Organic Manures on Yield Boron Use Efficiency and Nutrient Uptake by Tomato in Coastal Soil

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Boron (B) is an essential micronutrient for plant growth and development, playing a pivotal role in various physiological processes within the plant. In tomato cultivation, maintaining adequate boron levels is crucial for achieving optimal yield and quality. However, due to factors such as soil type, environmental conditions, and plant genetics, boron deficiency or inefficient utilization often poses challenges for growers, leading to reduced productivity and economic losses in coastal regions of

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Tamilnadu. This study investigates the effect of boron fertilization and boron enriched organic manures on yield boron use efficiency and nutrient uptake by tomato in coastal soil. A field experiment was conducted in the farmer's field at Varagurpettai coastal village, near Chidambaram in Cuddalore district of Tamilnadu, during July-November, 2022 using tomato variety NTH-777 as test crop. The experimental soil was sandy loam in texture and taxonomically classified as *Typic Ustifluvent* with pH-8.39, EC-4.07 dSm^{-1} and analysed low status of organic carbon (2.47 g kg^{-1}). The soil analysed low in alkaline $KMnO_4$–N (145.71 kg ha^{-1}) and Olsen-P (10.57 kg ha^{-1}) and medium in NH_4OAc-K (157.42 kg ha^{-1}). The available hot water soluble B content (0.27 mg kg^{-1}) was also low in soil. The various treatments imposed in the study included T_1–Control (RDF alone/100% NPK), T_2–RDF + Composted coirpith (CCP) @ 12.5 t ha^{-1}, T_3–RDF + CCP + Borax (B) @ 10 kg ha^{-1} through soil application (SA), T_4–RDF + CCP + Borax (B) through foliar application (FA) @ 0.5% twice @ pre flowering stage (PFS) and flowering stage (FS), T_5–RDF +CCP + Borax (SA) + (FA), T_6–RDF + CCP + Borohumate (BH) @ 15 kg ha^{-1} soil application (SA), T_7–RDF + CCP + Borohumate (FA), T_8–RDF + CCP + Borohumate (SA) + FA, T_9–RDF + Borax Enriched Composted coirpith (BECCP) @ 6.25 t ha^{-1} (SA), T_{10}–RDF + Borohumate Enriched Composted coirpith (BHECCP) @ 6.25 t ha^{-1} (SA), T_{11}–RDF + BECCP (SA) + Borax (FA) and T_{12}–RDF + BHECCP (SA) + Borohumate (FA). The experiment was laid out in a Randomized Block Design (RBD) with three replications. The results of the field experiment clearly indicated that integrated application of NPK fertilizer along with B enriched organic manures + biofertilizer and foliar spray of borohumate (BH) positively increased the growth, yield, quality and nutrient uptake by tomato. This treatment recorded the highest agronomic efficiency (4.10 t kg^{-1}), agro physiological efficiency (20.45 t kg^{-1}), apparent recovery efficiency (43.45%), physiological efficiency (14.30 t kg^{-1}) and boron use efficiency (410.34). This research contributes to the development of boron utilization dynamics and this study paves the way for future advancements in nutrient management strategies tailored to maximize yield and quality in tomato production systems.

Keywords: Boron; boron use efficiency; borohumate; coastal saline soil; tomato.

1. INTRODUCTION

Tomato plants, scientifically known as *Solanum lycopersicum*, are among the most beloved and widely cultivated vegetable plants worldwide. Belonging to the Solanaceae family, which also includes potatoes, eggplants, and peppers, tomatoes are renowned for their vibrant colors, versatile culinary applications, and nutritional value. Native to South America, particularly the Andes region, tomatoes have a rich history dating back thousands of years, with evidence of their cultivation by ancient civilizations like the Aztecs and Incas. Today, tomato plants are ubiquitous in gardens, farms, and even urban settings, cherished by home gardeners and commercial growers alike for their ease of cultivation and abundant yields. These plants typically exhibit a sprawling growth habit, with indeterminate varieties capable of producing fruit continuously throughout the growing season, while determinate types yield a more concentrated crop over a shorter period. The coastline of the Indian Peninsula is 8,129 kilometers long. The country's entire coastal region encompasses 10.78 million hectares. Only Tamil Nadu accounts about 6,80,622 hectares of coastal land, which makes up 26.8% of the total area of the coastal districts. Salt-affected soils cover over 1,125 million hectares worldwide. About 2.96 million saline and 3.79 million sodic soils, and 6.75 million hectares of salt-affected soils, are found in India. Nearly 2.04 L hectare of saline coastal soil is found in Tamil Nadu [1,2]. Sustainable agricultural production is greatly hampered by the coarse-textured soil that makes up, on average, 50% of the coastal districts [3,4,5,6].

"Problems of coastal sandy soils are beyond the capacity of the farmer's to address the exploitation of these stressed coastal ecosystems for arable cropping will increase the vegetables production to commensurate with the ever increasing population of our country. From this perceptive, it is important that the coastal sandy/sandy loam soils can be handled as the next frontiers for agriculture" [7,8]. In Tamil Nadu, the area under cultivation of tomato is 41,545 hectares with a production of about 8.15 lakh tonnes and productivity is 6.25 tonnes per hectare. Tomato is one of the commonly grown vegetable crops in coastal areas of Tamil Nadu. The short duration, low cost of cultivation and regular income due to staggered harvesting attracted many farmers in this region to cultivate tomato. However, the yield realized by the coastal farmers is around 12-15 t ha^{-1}, which is very low and far below as compared to national average yield of around 20-25 t ha^{-1}. The reasons being, poor organic matter and micronutrient status of soil and adoption of traditional management practices. The growth, yield and quality of tomato are largely influenced by the application of organic manures and inorganic fertilizers. Hence, there is an imperative need to increase the production of vegetables by way of adopting some improved cultivation practices such as foliar feeding of nutrients and growth stimulants in addition to the basal application of nutrients.

In this context, considering the inherent poor soil fertility, poor yield and economic condition of the coastal farmers, it is an imperative need that the enrichment of locally available organic wastes will be thought of, for achieving sustainable yield at minimum cost. Coastal areas of Tamil Nadu are endowed with a variety of organic wastes, which contain plant nutrients and several growth principles and enzymes, which can sustain soil health and crop production. Hence, in the present investigation, an attempt has been made with evaluation of different source of boron fertilizer, recommended dose of NPK along with boron enriched organic manures as well established the method of boron fertilization for increasing the productivity and quality of tomato and to improve the soil fertility status for sustainable soil health in coastal saline soils.

2. MATERIALS AND METHODS

A field experiment was conducted in the farmer's field at Varagurpettai coastal village, near Chidambaram in Cuddalore district of Tamilnadu, during July-November, 2022 using Tomato variety NTH-777 as test crop. The experimental soil was sandy loam in texture and taxonomically classified as *Typic Ustifluvent* with pH-8.39, EC-4.07 dS m^{-1} and analysed low status of organic carbon (2.47 g kg^{-1}). The soil analysed low in alkaline $KMnO_4$–N (145.71 kg ha^{-1}) and Olsen-P (10.57 kg ha^{-1}) and medium in NH_4OAc-K (157.42 kg ha^{-1}). The available hot water soluble B content (0.27 mg kg^{-1}) was also low in soil. The various treatments imposed in the study included T_1–Control (RDF alone/100% NPK), T_2–RDF + Composted coirpith (CCP) @ 12.5 t ha^{-1}, T_3–RDF + CCP + Borax (B) @ 10 kg ha^{-1} through soil application (SA), T_4–RDF + CCP + Borax (B) through foliar application (FA) @ 0.5% twice @ pre flowering stage (PFS) and flowering stage (FS), T_5–RDF +CCP + Borax (SA) + (FA), T_6–RDF + CCP + Borohumate (BH) @ 15 kg ha^{-1} soil application (SA), T_7 –RDF + CCP + Borohumate (FA), T_8–RDF + CCP + Borohumate (SA) + FA, T_9–RDF + Borax Enriched Composted coirpith (BECCP) @ 6.25 t ha^{-1} (SA), T_{10}–RDF + Borohumate Enriched Composted coirpith (BHECCP) @ 6.25 t ha^{-1}(SA), T_{11}–RDF + BECCP (SA) + Borax (FA) and T_{12}–RDF + BHECCP (SA) + Borohumate (FA). The experiment was laid out in a Randomized Block Design (RBD) with three replications. Fertilizer recommendation was followed at the rate of 200:250:250 kg of N: P_2O_5: K_2O per hectare was applied through urea, single super phosphate and muriate of potash to all experimental plots uniformly. Half of the N and entire P_2O_5 and K_2O were applied as basal and the remaining half dose of N was applied in two splits at flowering and fruit formation stage. Required quantities of different boron fertilizers like borax and borohumate were applied either through soil as well as foliar. Foliar application of borax and borohuamte (BH) @ 0.5 per cent twice at Pre Flowering Stage (PFS) and at Flowering Stage (FS) was applied as per the treatment schedule. Calculated quantities of boron enriched organic manures like borax enriched composted coirpith (BECCP) and borohumate enriched composted coir pith (BHECCP) were also applied to the soil as per treatment schedule. The biofertilizer *Azospirillum* @ 2 kg ha^{-1} was applied to all the experimental plots. Boron use efficiency is calculated as by formula

Based on yield and nutrient uptake following use efficiency parameters were worked out as formula suggested by Fageria [9]

i) Agronomic efficiency (kg ha^{-1}) = $(PY_B - PY_C)/S_a$
ii) Physiological efficiency (kg ha^{-1}) = $(Y_B - Y_C)/(U_S - U_C)$
iii) Agro physiological efficiency = $(PY_B - PY_C)/(U_S - U_C)$
iv) Apparent recovery efficiency = $(U_B - U_C)/S_a X100$
v) Boron use efficiency = PE X ARE

Where PY_B is fruit yield of boron applied plots, PYC is the fruit yield of unfertilized plots, S_a is total amount of boron applied, Y_B is the fruit and stover yield of boron treated plots, Y_C is the fruit and stover yield of unfertilized plots, U_B is the boron uptake in fruit and stover yield of boron applied plots and U_C is the uptake of boron in fruit and stover yield of untreated plots.

3. RESULTS AND DISCUSSION

3.1 Growth Characters of Tomato (Table 1)

The application of boron enriched organics manures along with boron (B) fertilization favourably increased the growth characters of tomato. Among the various sources of boron tried, application of boron through borohumate was superior over borax. Among the different methods of B fertilization both soil and foliar application was significantly superior as compared to soil and foliar alone. Among the two sources of boron enriched organics tried, application of borohumate enriched composted coirpith (BHECCP) was superior over borax enriched composted coirpth (BECCP).

Among the various treatments, the treatment (T_{12}), combined application of recommended dose of NPK + borohumate enriched composted coirpith (BHECCP) @ 6.25 t ha^{-1} through soil application along with foliar application of borohumate @ 1.0 per cent twice at pre flowering stage (PFS) and at flowering stage (FS) recorded the highest growth characters of plant height (60.25), No. of branches plant^{-1} (109.18) and dry matter production (132.19) at harvest stages of tomato, respectively. This was followed by the treatments which received RDF along with B as borax enriched composted coirpith (BECCP) @ 6.25 t ha^{-1} through soil application (SA) and foliar spray of borax @ 0.5 per cent twice (T_{11}), RDF + borohumate enriched composted coirpith (BHECCP) @ 6.25 t ha^{-1} through soil application (T_{10}) and treatment T_9, which supplied RDF + BECCP @ 6.25 t ha^{-1} which recorded a plant height, No. of branches plant^{-1} and dry matter production of 25.31, 118.11 and 111.37 cm at harvest stage, respectively.

This was followed by the treatments individual application of borohumate or borax either through soil or foliar and or both along with organics (without B enriched organics) treatments like T_8, RDF + borohumate (BH) @ 15 kg ha^{-1} both soil as well as foliar application of borohumate @ 0.5% twice and treatment T_5, RDF + CCP along with borax through soil and foliar application which recorded the lowest mean growth characters *viz.,* plant height of 104.29 cm, No. Of branches plant^{-1} of 112.22 and dry matter production of 97.25 cm at harvest stgae of tomato, respectively as compared to above said enriched organics applied treatments. However, the treatment T_5 was found to be comparable with RDF + CCP @ 12.5 t ha^{-1} along with borohumate (BH) @ 15 kg ha^{-1} through soil application alone (T_6). This was followed by the treatments arranged in the descending order like T_3>T_7>T_4 and T_2. The control (T_1) produced the lowest growth characters over all other treatments (RDF alone).

Table 1. Effect of boron fertilization and boron enriched composted coirpith on the growth characters of tomato

Treatments	Plant height (cm)			Number of branches plant^{-1}			Dry matter production (t ha^{-1})		
	FS	FFS	HS	FS	FFS	HS	FS	FFS	HS
T_1	24.78	47.29	58.96	3.05	5.54	6.74	2.03	1.65	6.55
T_2	28.30	53.14	66.41	4.09	7.11	8.46	3.06	2.78	7.78
T_3	39.02	71.61	87.23	6.83	11.92	12.77	5.58	5.52	11.54
T_4	31.36	59.38	73.25	5.03	8.48	9.82	3.69	3.60	9.21
T_5	44.47	79.69	97.25	7.44	13.31	14.09	6.32	6.46	12.98
T_6	43.72	77.35	94.37	7.38	13.26	14.04	6.24	6.35	12.86
T_7	34.91	65.27	80.29	5.86	10.30	11.33	4.53	4.54	10.29
T_8	48.27	85.46	104.29	7.98	14.68	15.29	6.89	7.48	14.15
T_9	51.18	91.68	111.37	8.53	15.85	17.21	8.09	8.99	15.52
T_{10}	54.15	97.34	118.11	9.11	17.39	18.58	8.58	10.32	16.85
T_{11}	57.27	103.44	125.31	9.66	18.78	19.87	9.56	12.79	18.24
T_{12}	60.25	109.18	132.19	10.19	19.99	21.12	10.15	14.75	19.34
SE_D	1.38	2.69	3.22	0.25	0.53	0.57	0.26	0.36	0.48
CD (p=0.05)	2.88	5.61	6.71	0.52	1.10	1.20	0.56	0.75	1.03

The treatment T_{12}, recorded the maximum plant height, number of branches plant^{-1} and dry matter production and this might be due to the increased nutrient supply with the addition of chemical fertilizer and boron enriched organics. Further, foliar spray of boron as borohumate might have induced the synthesis of chlorophyll content and direct effect of plant growth like enzymatic activity which in turn resulted in higher vegetative growth parameters *viz.,* plant height, number of branches per plant and dry matter production (DMP) of tomato. These findings also are in conformity with several workers of Asri et al. [10] Kumar et al*.* (2016) and Sathiyamurthi et al. [11].

3.2 Yield of Tomato (Table 2)

The tomato responded well for the boron nutrition fertilizers (borax or borohumate) application. The significant influence of boron fertilization (soil or foliar and or both), recommended dose of NPK along with B enriched organics in increasing the fruit and stover yield of tomato was well documented in the present study.

The yield realized under the nutrient poverished coastal saline soil, the highest fruit yield (29.15 t ha^{-1}) and stover yield (19.38 t ha^{-1}) was recorded with combined application of recommended dose of fertilizer (RDF) + borohumate enriched composted coirpith (BHECCP) @ 6.25 t ha^{-1} through soil along with foliar spray of borohumate (BH) @ 0.5 per cent twice at pre flowering and flowering stage (T_{12}). This was followed by the treatments $T_{11,}$ (RDF + borax enriched composted coirpith (BECCP) @ 6.25 t ha^{-1} through soil application and foliar application of borax @ 0.5%), T_{10} (RDF + BHECCP @ 6.25 t ha^{-1}) and T_9 (RDF + BECCP @ 6.25 t ha^{-1}) these treatments which recorded the fruit (28.38, 27.63 and 26.91 t ha^{-1}) and stover (18.91, 18.38 and 17.71 t ha^{-1}) yield of tomato, respectively. With regards to application of recommended dose of NPK, boron nutrition either through soil or foliar or both along with organics (without B enriched organics) treatmentslike$T_{8,}$ (RDF + CCP @ 12.5 t ha^{-1} + borohumate @ 15 kg ha^{-1} through SA + borohumate @ 0.5% through FA) and T_5 (RDF + borax @ 10 kg ha^{-1} (SA) + borax @ 0.5% (FA) + CCP @ 12.5 t ha^{-1}). However, the treatment T_5 was on par with treatment T_6 (RDF + borohumate @ 15 kg ha^{-1} (SA) + CCP @ 12.5 t ha^{-1}).

This was followed by application of B as borohumate or borax either through soil or foliar alone treatments *viz.,* T_3 (RDF + CCP + Borax @ 10 kg ha^{-1} through soil alone). T_7 (RDF + CCP + BH @ 0.5% through foliar alone) and T_4 (RDF + CCP + Borax @ 0.5% through foliar alone) these treatments which recorded the lowest fruit yield (24.63, 23.88 and 23.11 t ha^{-1}) and stover yield (16.29, 15.77 and 15.31 t ha^{-1}) of tomato, respectively as compared to above said B-enriched composted coirpith treatments. This was followed by the treatment T_2 (RDF + CCP @ 12.5 t ha^{-1}).

Table 2. Effect of boron fertilization and boron enriched composted coirpith on the yield of tomato

Treatments	Yield (t ha^{-1})		Percent increase over control (%)	
	Fruit	Stover	Fruit	Stover
T_1	21.68	14.18	_	_
T_2	22.41	14.77	3.36	4.16
T_3	24.63	16.29	13.60	14.88
T_4	23.11	15.31	6.59	7.96
T_5	25.44	16.79	17.34	18.40
T_6	25.32	16.71	16.78	17.84
T_7	23.88	15.77	10.14	11.21
T_8	26.18	17.22	20.75	21.43
T_9	26.91	17.71	24.12	24.89
T_{10}	27.63	18.38	27.44	29.61
T_{11}	28.38	18.91	30.90	33.35
T_{12}	29.15	19.38	34.45	36.67
SE_D	0.32	0.18	–	–
CD (p=0.05)	0.68	0.38	–	–

"Among the various treatments, the treatment (T_{12}), which received recommended dose of NPK + borohumate enriched composted coirpith along with boron nutrients as borohumate through both soil (BHECCP @ 6.25 t ha^{-1}) and foliar (BH @ 0.5%) application recorded a fruit and stover yield of 29.15 and 19.38 t ha^{-1} which was 34.45 and 36.67 per cent increase over control or 100 per cent NPK alone (without B and enriched organics). The control treatment T_1, 100 per cent NPK alone recorded a lowest fruit (21.68 t ha^{-1}) and stover (14.18 t ha^{-1}) yield of tomato as compare to all other treatments". [12].

Overall improvement in fruit and stover yield of tomato was due to the application of recommended dose of NPK fertilizers along with borohumate enriched composted coirpith @ 6.25 t ha^{-1}. This could be attributed to the fact that the nutrients in the borohumate are released gradually through the process of mineralization, maintaining optimal soil B levels over entire or prolonged periods of crop growth. Some of the humic substances are released during mineralization and may act as a chelate forms which also helps in increasing the absorption of boron and other essential micronutrients. The earlier report of Yadav et al. [13] and Punithraj et al. [14] supports the present findings. Further, the borohumate derived from humic acids are known to form chelates with other ions and thus it improves translocation of the nutrients within the plant system and may improve the nutrient use efficiency by providing more balanced supply of nutrients. The present result was in harmony with the findings of Venkatakrishnan et al. [15] and Yadav et al. [16] in tomato. The increased tomato yield due to the application of different forms of humic substance and NPK fertilizer have already been well documented by Vetriselvan [17], Abdellatif et al. [18], and Venkatakrishnan et al. [19].

3.3 Boron Use Efficiency (Table 3)

The boron use efficiency (BUE) parameters *viz.,* agronomic efficiency, agro-physiological efficiency, physiological efficiency, apparent efficiency recovery and boron use efficiency was positively influenced due to the different modes of boron fertilization along with boron enriched CCP and recommended NPK fertilizer.

Among the various B enriched organics applied treatment the application of 100 per cent recommended dose of NPK + BHECCP @ 6.25 t ha^{-1} through soil (T_{10}) recorded the highest agronomic efficiency (4.10 t kg^{-1}), agro physiological efficiency (20.45 t kg^{-1}), apparent recovery efficiency (43.45%), physiological efficiency (14.30 t kg^{-1}) and boron use efficiency (410.34). This was followed by the treatments. T_9 – RDF + BECCP @ 6.25 t ha^{-1} through soil, T_{12} – RDF + BHECCP (SA) + Borohumate (FA) and T_{11} – RDF + BECCP (SA) + Borax (FA) through soil, which recorded the boron use efficiency values of 307.65, 136.51 and 117.54, respectively.

Table 3. Effect of boron fertilization and boron enriched composted coirpith on the boron use efficiency parameters

Treatments	Agronomic efficiency (tonnes kg^{-1})	Agro physiological efficiency (tonnes kg^{-1})	Physiological efficiency (tonnes kg^{-1})	Apparent Nutrient recovery (%)	Boron use efficiency (PE × ARE)
T_1	-	-	-	-	-
T_2	-	-	-	-	-
T_3	1.74	13.88	14.05	12.35	173.53
T_4	0.36	12.13	12.55	2.50	35.75
T_5	0.66	11.65	12.13	5.44	65.96
T_6	2.51	14.02	14.30	20.01	251.03
T_7	0.55	13.36	13.75	4.03	55.00
T_8	0.83	10.19	9.44	7.71	82.57
T_9	3.08	9.03	10.06	30.59	307.65
T_{10}	4.10	20.45	10.71	43.45	410.34
T_{11}	1.18	8.78	9.18	12.81	117.54
T_{12}	1.37	8.49	8.86	15.41	136.51

This was followed by the treatments which received B as borax/borohumate either through soil or foliar or combination of both along with organics (without B enriched CCP) applied treatments. The treatment T_6 application RDF + CCP + BH @ 15 kg ha^{-1} through soil recorded the lowest agronomic efficiency (2.51 t kg^{-1}), agro physiological efficiency (14.02 t kg^{-1}), apparent nutrient recovery (20.01%), physiological efficiency (14.07 t kg^{-1}) and boron use efficiency (251.03).

The higher value of boron use efficiency was recorded with application of boron through borohumate enriched organics. This might be due to favorable effect of boron on efficient utilization during entire crop growth periods [20]. The positive effect of boron on boron use efficiency could be attributed due to the favorable effect of boron alters the permeability of plasma lemma at the root surface in such a way that boron absorption by roots increases and greater utilization of applied boron by tomato [21].

Nutrient use efficiency can be defined as the ability of plants to produce maximal amounts of DMP or yield per each increment of nutrient accumulation [22]. The highest boron use efficiency obtained in the present investigation was due to the application of recommended dose of fertilizer + borohumate @ 15 kg ha^{-1} + borax @ 10 kg ha^{-1} along with fortified organic manures of BECCP and BHECCP. This treatment recorded the highest boron use efficiency of 195.33 tonnes $tonnes^{-1}$. Further, the tomato hybrid showed marked variation in boron use efficiency parameters *viz.,* agronomic efficiency, physiological efficiency, agro-physiological efficiency, apparent recovery and boron utilization efficiency. The highest use efficiency in integrated treatments may be due to very small amounts of B used from the fertilizer in slow and steady rate [23]. This might be due to the higher yield and uptake obtained from the treatment T_{12}, which concordantly increased the boron use efficiency. This was confirming with the earlier findings of Tariq et al. [24] and Kamaleshwaran [25].

3.4 Major nutrients uptake (Table 4)

“The uptake of major nutrients by tomato at all the growth stages as well as by fruit and stover was also significantly increased with boron fertilization and recommended NPK along with B enriched organics” [12].

Both the sources of B studied, there was a significant increase in NPK uptake by tomato over control. Among the sources of boron, application of B through borohumate performed well and registered the highest NPK uptake by tomato fruit and stover as compared to borax. Among the various treatments, the combined application of recommended NPK along with BHECCP @ 6.25 t $ha^{-1}$and foliar spray of borohumate @ 0.5 per cent twice (T_{12}) registered the highest uptake of NPK at all the growth stages.

This was followed by the treatments T_{11} (RDF + BECCP @ 6.25 t ha^{-1} through soil + borax @ 0.5% through foliar spray), T_{10} (RDF + BHECCP @ 6.25 t ha^{-1} through soil alone), T_9 (RDF + BECCP @ 6.25 t ha^{-1} through soil alone) and T_8 (RDF + CCP @ 12.5 t ha^{-1} + borohumate @ 15 kg ha^{-1} as SA + borohumate @ 0.5% as FA). The treatments $T_{11,}$ T_{10}, T_9 and T_8 recorded a significant nitrogen (51.63, 48.83, 46.01 and 43.23 kg ha^{-1} by fruit and 88.66, 83.71, 79.04 and 74.18 kg ha^{-1} by stover), phosphorus (21.89, 20.61, 19.40 and 18.05 kg ha^{-1} by fruit and 27.91, 26.39, 24.87 and 23.21 kg ha^{-1} by stover) and potassium uptake (75.85, 71.78, 67.75 and 63.64 kg ha^{-1} by fruit and 123.32, 116.66, 110.12 and 103.52 kg ha^{-1} by stover). This was followed by the treatments T_5 (RDF + CCP + borax @ 10 kg ha^{-1} SA + borax as FA @ 0.5%) and treatment T_6 (RDF + CCP + borohumate as SA alone). The treatment T_5 and T_6 recorded a comparable nitrogen (39.97 and 40.39 kg ha^{-1}), phosphorus (15.96 and 16.81 kg ha^{-1}) and potassium (58.05 and 59.49 kg ha^{-1}) uptake by fruit in tomato, respectively. “This was followed by the treatments are arranged in the descending order like T_3>T_7>T_4 and T_2. These treatments were also statistically significant. The treatment T_1, application of 100% NPK alone (without organics and B) recorded the lowest NPK uptake at all growth stages of tomato” [12].

The reason behind the increased N uptake was supposed to be due to the better use efficiency of applied N fertilizers in the presence of borohumate coupled with the retarded nitrification process enabling the slow availability of applied N and reduced the losses of nitrogen through denitrification and leaching which resulted in higher N uptake, similar finding were reported by Xu et al. [26].

Table 4. Effect of boron fertilization and boron enriched composted coirpith on the major nutrients uptake (kg ha^{-1}) by tomato

Treatments	Nitrogen				Phosphorus				Potassium			
	FS	FFS	HS		FS	FFS	HS		FS	FFS	HS	
			Fruit	Stover			Fruit	Stover			Fruit	Stover
T_1	8.06	11.47	23.16	40.66	3.55	6.04	7.80	11.66	13.31	36.48	35.65	63.03
T_2	9.53	13.02	26.70	46.32	4.83	7.52	9.32	13.61`	15.17	40.95	40.37	69.95
T_3	14.16	17.90	36.23	62.09	8.38	11.77	14.39	18.94	20.83	55.33	53.66	87.78
T_4	11.05	14.49	30.37	51.29	5.81	8.87	10.86	15.30	17.02	45.78	44.86	77.06
T_5	15.70	19.36	40.39	69.34	9.18	13.21	16.81	21.67	23.24	62.53	59.49	96.95
T_6	15.61	19.28	39.37	67.33	9.09	12.99	15.96	20.47	22.68	60.18	58.05	94.45
T_7	12.78	16.25	33.28	57.11	7.16	10.42	12.71	17.25	18.98	50.47	49.14	83.93
T_8	16.82	20.76	43.23	74.18	9.87	14.16	18.05	23.21	24.88	66.82	63.64	103.52
T_9	18.05	22.17	46.01	79.04	10.61	15.11	19.40	24.87	26.50	71.06	67.75	110.12
T_{10}	19.26	23.56	48.83	83.71	11.35	16.08	20.61	26.39	28.20	75.31	71.78	116.66
T_{11}	20.43	24.96	51.63	88.66	12.05	17.06	21.89	27.91	29.88	79.62	75.85	123.32
T_{12}	21.58	26.34	54.38	93.48	12.73	17.99	23.12	29.49	31.54	83.85	79.97	129.86
SE_D	0.52	0.64	1.32	2.25	0.31	0.43	0.57	0.72	0.77	2.02	1.92	3.12
CD (p=0.05)	1.10	1.35	2.76	4.73	0.66	0.91	1.20	1.51	1.61	4.21	4.00	6.51`

In addition, applied NPK resulted in better root growth and increased physiological activity of roots to absorb more phosphorus. These findings are in conformity with Bentamra et al. [27]. Moreover, the higher root growth of tomato due to addition of boron had better mobilization of phosphorus resulted in more accumulation of P content in plants. Similar results were noticed in Kumar et al. [28] in radish; Kalaiselvi [29] and Sarangthem et al. [30] in tomato.

Increased K uptake might be due to better plant growth leading to higher uptake of nutrients and further on the stimulatory effect of B in absorption of potassium. These results are in accordance with the findings of Islam et al. [31]. The ready availability of K and other nutrients from inorganic sources produced adequate biomass, which resulted in better nutrient uptake of the crop. These findings are in agreement with Singh et al. [32]. "Further added B-enriched organics improved the organic carbon content of soil through decomposition, which helped in the release of organically bound macro and micronutrients in soil" [12]. Noor et al. [33] and Gao et al. [34] also reported such increased availability of nutrients with organics.

3.5 Boron uptake (Fig. 1)

The effect due to the different methods (soil/foliage) and sources of boron (borohumate/borax) application along with recommended dose of NPK and B enriched composted coirpith had significant influence on boron uptake by tomato at flowering stage (FS), fruit formation stage (FFS) and at harvest stage (HS).

Among the various treatments, the highest B uptake by fruit (1124.12 g ha^{-1}) and stover (935.15 g ha^{-1}) in tomato was recorded with the application of recommended dose of NPK + borohumate enriched CCP (BHECCP) @ 6.25 t ha^{-1} through soil and foliar spray of borohumate @ 0.5 per cent twice (T_{12}). This was followed by application of RDF + BECCP @ 6.25 t ha^{-1} through soil + borax @ 0.5% through foliar spray (T_{11}). This was followed by the treatments, which received both the B sources (Borohumate and Borax) with single mode of fertilization either soil or foliar applied treatments. The treatment T_{10} - RDF + BHECCP @ 6.25 t ha^{-1}, T_9 - RDF + BECCP @ 6.25 t ha^{-1} through soil application alone and T_8 - RDF + CCP @ 12.5 t ha^{-1} along with borohumate (BH) @ 15 kg ha^{-1} (SA) + borohumate @ 0.5% (FA) recorded a lowest B uptake of tomato as compared to above said treatment (boron nutrition both soil and foliar along with B enriched organics).

This was followed by application of RDF + CCP along with soil application of borax @ 10 kg ha^{-1} + borax @ 0.5 per cent foliar spray (T_5). However, this was found to be on par with treatment (T_6) which received RDF + CCP along with borohumate (BH) @ 15 kg ha^{-1} through soil and recorded a comparable B uptake of 838.96 and 826.50 g ha^{-1} by fruit and 693.45 and 681.01 g ha^{-1} by stover, respectively. This was followed by the treatments significantly arranged in the descending order as $T_3 > T_7 > T_4 >$ and T_2. These treatments were also statistically significant.

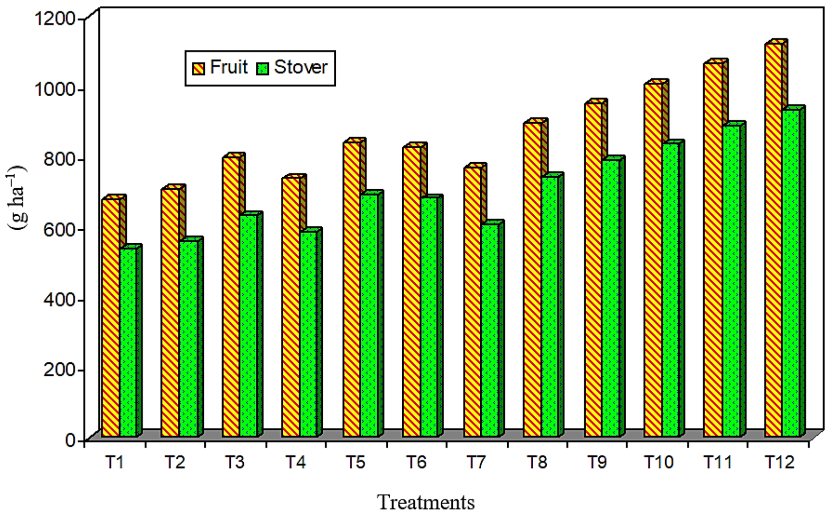

Fig. 1. Effect of boron fertilization and boron enriched composted coirpith on the boron uptake (g ha^{-1}) by tomato

Application of 100 per cent NPK alone (T_1) recorded a comparatively lower B uptake of 679.27 g ha^{-1} by fruit and 537.03 g ha^{-1} by stover as compared to application of RDF along with CCP (T_2) which recorded a B uptake of 708.74 and 560.60 g ha^{-1} by fruit and stover in tomato, respectively.

The increased B uptake might be due to the addition of micronutrients as impurities along with the fertilizers. Further, the application of borohumate, might have increased the availability through enhanced mineralization and chelation action, which increased the absorption and utilization of these nutrients. The report of Karaman et al*.* [35], Ekinci et al. [36] and Kamaleshwaran [25] supported the present findings [37].

4. CONCLUSION

The present investigation clearly concluded that the beneficial role of boron enriched organics along with boron fertilization for increasing tomato production in coastal saline soil. Application of recommended dose of NPK + borohumate enriched composted coirpith @ 6.25 t ha^{-1} (BHECCP) along with borohumate @ 0.5 per cent twice at critical stages like pre flowering stage (PFS) and flowering stage (FS) through foliar spray was identified as the best treatment combination and to be recommended to the vegetables growers of coastal farmers to realize the maximum boron use efficiency (BUE), yield, nutrient uptake and sustain soil health in coastal saline soil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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