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Status and Requirement of Boron for Tropical Tuber Crops Under Laterite (Typic Kandi Ustult) Soils

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Abstract

Tropical tuber crops also require the micronutrient B for its growth and productivity as in the case of all other crops. The very low B content in the major tropical tuber crops growing soils of Kerala could cause the manifestation of B deficiency symptoms both in vegetative parts and tubers in the case of cassava and sweet potato. The recent occurrence of symptoms akin to hollow/brown heart of potato, in yams (*Dioscorea*), necessitated to take up experiments related to B nutrition to understand the etiology of this problem. Since the manifestation was noticed in a typical laterite soil (Typic Kandi Ustult) of the farm of ICAR-CTCRI and under similar soils of the State, a rapid nutrient status appraisal was made for the five blocks of CTCRI farm for nutrients viz., available B and exchangeable Ca as there exists a synergism between these two nutrients. A sorption study too was conducted to predict the rate of application of B for soils of varying B status. A total of 95 soil samples collected from these blocks taking into account the terrain and present cropping/fallow were analysed. Wide variation was seen in the available B status ranging from 0.14-0.419 ppm for block I and II, 0.172-0.419, 0.172-0.848, 0.150-1.052 ppm for block III, IV and V respectively with mean values as 0.317, 0.242, 0.289, 0.331 and 0.356 ppm respectively. The mean exchangeable Ca content of the soils of these blocks were 0.896, 1.015, 0.640, 0.989, 0.877 meq 100 g^{-1} soil with ranges as 0.565-1.303, 0.741-1.387, 0.534-0.866, 0.762-1.215 and 0.591-1.254 meq 100 g^{-1} soil respectively. To understand the interaction between these nutrients, the correlation worked out indicated synergism or significant positive correlation ($r=0.537$) only in block V. Sorption study could find a linear increase in the quantity of B extracted in the soils of varying B contents ranging from 0.1-1.0 ppm under addition of incremental rates of B from 0.25 to 4.0 ppm. The inverse prediction function method employed to predict the quantity of B to be applied to attain soil B status to either the soil critical level of B (0.5 ppm), double (1.0 ppm) and thrice (1.5 ppm) the critical levels in soils of the above B status (0.1-1.0 ppm) was found as 0.78-3.09, 1.80-7.21 and 7.4-11.33 ppm respectively. Though the low soil available B and exchangeable Ca content can be attributed as one of the reasons for the problem manifested in yams, detailed studies are needed to explore the role of abiotic factors especially moisture and heat stress in the dynamics of these nutrients at different growth stages of the crop.

Key words: Laterite, available B, exchangeable Ca, sorption curve, inverse prediction function, yams, hollow/brown heart, abiotic stress

Introduction

Among the 17 essential elements required for the growth and productivity of crops, micronutrients like zinc (Zn), copper (Cu) and boron (B) are significant mainly for the laterite (Ultisols) and sandy loam soils (Entisols). B is one of the non metal micronutrient required for the normal growth and productivity of plants especially for the development and differentiation of tissues, particularly growing tips, phloem and xylem (Sakal and Singh, 1995). It occurs in very low concentration in the earth's crust and plays an important role in sugar translocation. There is widespread deficiency of B noticed in many parts of India and incidentally deficiency symptoms associated with it too. In Kerala, the major tuber crops growing soils viz., laterites and sandy loam soils are deficient in B. Rajasekharan et al., (2014), Mini and Usha (2015) and Anju et al., (2019) reported wide spread deficiencies of B in the laterite and sandy loam soils of Kerala.

Ouellette (1958) and Rashid (1996) justified the severe B deficiency of sandy soils due to its coarse texture which is well drained and hence highly leachable. Similarly Santhosh (2013) also attributed the B deficiency of soils to the clay, phosphorus (P) as well as the organic matter content which in turn govern the B supplying power of the soils. B recommendations both as soil as well as foliar was evolved by many researchers in different crops (Sakal, 2001; Shankar et al., 2005; Santhosh, 2013). In the case of tropical tuber crops, boron application rates both soil and foliar were standardized, in sweet potato (Byju et al., 2010), cassava (Susan John et al., 2017, 2019) and elephant foot yam (Sahoo et al., 2015, Anju et al., 2020). A nutrient management strategy of secondary and micronutrients for sweet potato and elephant foot yam comprising of nutrients viz., Ca, Mg, Zn and B, both soil and foliar including an integrated package for correcting the tuber cracking very common in cassava and sweet potato due to B deficiency was evolved. B fertilizers should be uniformly applied with utmost caution to the soil because of the narrow range between deficiency and toxicity. It is very important to have more precaution with respect to the concentration of B for foliar application as excess concentration can result in toxic symptoms. Now, there are reports from many parts of the State regarding the symptom akin to potato brown heart/hollow heart in greater yam (*Dioscorea alata*) and white yam (*Dioscorea rotundata*). Among the many different reasons attributed to the same, B deficiency also was suspected. Since the symptom was found very severe at on station at ICAR-CTCRI in Block IV of the farm, where the soil is typical laterite belonging to the soil order Ultisol with Kandic soil horizon and Ustic soil moisture regime, we have made an attempt to determine the B status of the five different blocks of ICAR-CTCRI through a rapid appraisal and to arrive at the required B rate for soils of varying B status through a sorption study.

Materials and Methods

The two important objectives of the study were to estimate the status of B in the laterite soils where the suspected B deficiency in yam was observed and to recommend the rate of application of B for soils deficient in that nutrient. In this regard, two experiments were conducted viz., rapid appraisal of the B status of a Typic Kandi Ustult which is a typical laterite and sorption study to determine the B adsorbing capacity of the soil to arrive at the optimum dose of application for soils with varying soil available B.

Rapid appraisal of the B status of a Typic Kandi Ustult

The appraisal was made for the typical laterite soils spread over the five different blocks of ICAR-CTCRI farm. These five blocks are having a total area of 45 hectares distributed as 13.024, 12.02, 4.18, 7.38 and 7.38 ha respectively for blocks 1, 2, 3, 4 and 5. Representative soil samples were collected from each block taking into account mainly the terrain of the land, crops grown/ fallow. The map of each block with plot numbers are given in Fig.1. A total of 25, 16, 14, 18 and 22 samples

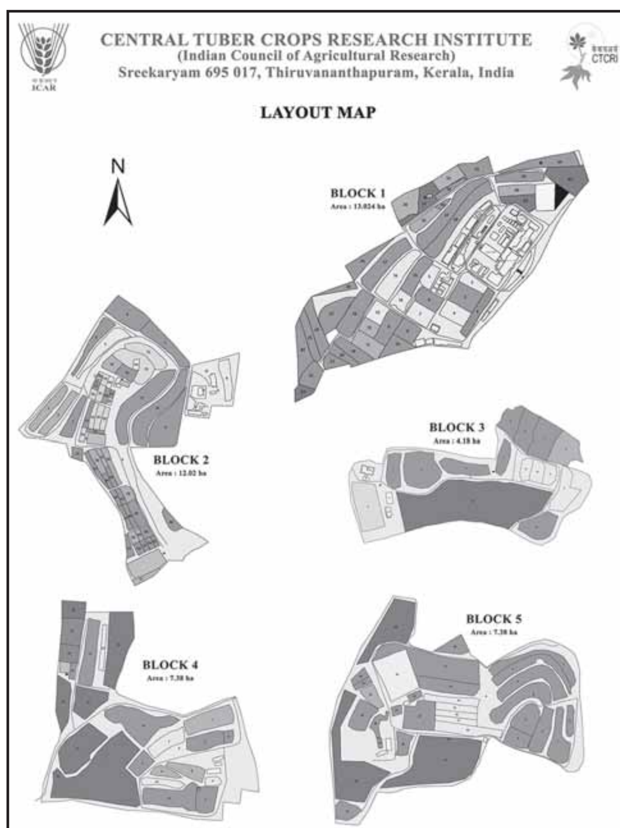

Fig.1. Layout map of five blocks of CTCRI farm

were collected respectively from these five blocks. These samples after proper drying under shade and sieving through 2 mm sieve was analyzed for available B using azomethine H method (Singh et al., 2005). Since there exists a synergism between available B and exchangeable Ca, these samples were analyzed for exchangeable Ca too (Singh et al., 2005). The details of soil sampling from the plots marked in the maps of the five blocks with sample numbers indicating the plots from where the samples were mixed and made as one sample is clearly given in Table 1.

Sorption study

On analysis of the soil samples, it is seen that, the B status of the soils of ICAR-CTCRI farm ranged from 0.1-1 ppm. The purpose of this study was to see the B release under different concentrations of added B in soils of different B status to simulate field conditions. This in turn can give information either to correct the observed B deficiency symptom or as a preventive measure in managing the occurrence of any B deficient symptoms for soils with low B status. The study could also give details on the amount of B to be applied in soils of varying

Table 1. Soil sampling in the five blocks indicating plot numbers and sample numbers (as per the map attached)

Block I		Block II		Block III		Block IV		Block V	
Sample No.	Plot Nos.	Sample No.	Plot Nos.	Sample No.	Plot Nos.	Sample No.	Plot Nos.	Sample No.	Plot Nos.
1	2,3,4	1	1	1	1	1	1	1	1
2	6,7	2	2	2	2	2	4,5	2	2,8
3	8,9,10	3	3	3	3	3	7	3	17
4	15,5,14	4	4	4	4	4	6,8,11	4	18
5	16	5	5	5	5	5	3	5	19
6	17	6	6,7	6	6	6	9,10	6	16
7	18	7	17,23,24, 25,26,27,28	7	7, 12	7	12	7	20,21,22
8	11,12,13	8	29,30,31, 32,33,34	8	7,8	8	13	8	23
9	29	9	12,13,14, 15,16	9	9,10	9	14(1)	9	27
10	28	10	8	10	11,14(1)	10	14(2)	10	28
11	19	11	6,10	11	14(2), Fallow	11	14(3)	11	24,29
12	20,21	12	11	12	14(3)	12	15,16,17	12	31
13	22,24,25	13	36,37,38, 39,40,41	13	14(4)	13	18,19	13	30
14	26	14	42,43,44, 45,46,47, 48,49,50, 51,52,53, 54,55	14	14(5)	14	20	14	32
15	37	15	56	-	-	15	21	15	10,11,12
16	38	16	57	-	-	16	22	16	13,14
17	35,36	-	-	-	-	17	23	17	15
18	30	-	-	-	-	18	15	18	5,9
19	31,32,34	-	-	-	-	-	-	19	3
20	39	-	-	-	-	-	-	20	4
21	40	-	-	-	-	-	-	21	6
22	44	-	-	-	-	-	-	22	7
23	43	-	-	-	-	-	-	-	-
24	Fallow	-	-	-	-	-	-	-	-
25	23	-	-	-	-	-	-	-	-

B concentration to attain either the critical level of B (0.5 ppm), twice or thrice the critical level.

For conducting this study, soils having B concentrations of 0.1 ppm in the different blocks were mixed and similar mixing was done for soils having 0.2 , 0.3, 0.4, 0.5, 0.6, 0.7, 0.9 and 1. 0 ppm B and hence one composite sample each of the above ppm was prepared and was kept for sorption study. These soil samples (5 g) in duplicate were added with 5 ml each of 0.25, 0.5, 1.0, 2.0 and 4 ppm B and incubated for 3 days under normal environmental condition till the soil became air dry. These samples were then analyzed for soil available B (Singh et al., 2005). B solutions with varying concentrations was made by dissolving 0.88 g $Na_2B_4O_7$. 10 H_2O in 1000 ml resulting in 100 ppm B followed by appropriate dilution. Sorption curve was fitted by plotting added B on the X axis and extracted B on the Y axis (Hunter, 1984).

Statistical analysis

Correlation between available B and exchangeable Ca was done to see the synergism / antagonism existing between the two nutrients (SAS, 2010). From the sorption study, the rate of application of B for soil with varying B status ranging from 0.1-1.0 ppm was predicted using an inverse prediction function method available in the R package chem Cal (Johannes, 2021) and calculation as per Massart et al., (1997).

Results and Discussion

Rapid appraisal of the available B status of the Typic Kandi Ustult

As per Table 2 below, among the blocks, not much variation was seen in the B status. The B status of these blocks ranged from 0.14-0.419 ppm with mean value as 0.317 and 0.242 ppm under block I and II and 0.172-0.419 ppm and 0.172-0.848 ppm with mean values as 0.289 and 0.331 ppm at block III and IV and 0.150-1.052 ppm with mean value as 0.356 ppm at block V. According to Tandon (1993), the general critical level of soil available B is 0.5 ppm. Anju et al., (2020) reported an available B status of 0. 683 and 0. 78 ppm in Agro Ecological Unit (AEU) 3 and AEU 9 respectively based on weighted average method. Susan John et al., (2007) reported an available B status of 0.76 ppm for the red loam soils (Oxisols) of Kerala. The very low status (compared to the critical level of B) of B observed in the present study under the laterite soils can be attributed to the high P (40-160 kg ha^{-1}) and low organic carbon (less than 0.5%) content of this soil and the high rainfall prevailing in the tropical humid region as per Santhosh (2013).

The data on soil available B (ppm) of the soils of the five blocks are given in Table 2.

Rapid appraisal of the exchangeable Ca status of the Typic Kandi Ustult

Since there exists synergism between available B and exchangeable Ca, exchangeable Ca also was determined. As there was no symptom expression in yam grown in Block II of the farm for these crops and already the synergism between B and Ca is known as higher calcium levels served to overcome the seemingly detrimental effects of excessive boron (Fox and Albrecht, 1958), the

Table 2. Available B status of the soils of the five Blocks of ICAR-CTCRI Farm

Sample No.	Available B (ppm)				
	B I	B II	B III	B IV	B V
1	0.333	0.204	0.387	0.204	0.258
2	0.397	0.183	0.344	0.269	0.322
3	0.279	0.140	0.462	0.322	0.344
4	0.344	0.215	0.226	0.301	0.333
5	0.387	0.193	0.247	0.236	0.730
6	0.301	0.215	0.204	0.258	0.344
7	0.269	0.387	0.236	0.451	0.204
8	0.183	0.344	0.333	0.408	0.226
9	0.354	0.419	0.226	0.172	1.053
10	0.311	0.290	0.419	0.848	0.344
11	0.290	0.172	0.387	0.290	0.612
12	0.344	0.215	0.215	0.354	0.236
13	0.397	0.236	0.172	0.301	0.215
14	0.397	0.279	0.193	0.236	0.161
15	0.419	0.226	-	0.183	0.601
16	0.365	0.161	-	0.322	0.397
17	0.387	-	-	0.344	0.269
18	0.140	-	-	0.462	0.226
19	0.172	-	-	-	0.247
20	0.322	-	-	-	0.279
21	0.269	-	-	-	0.150
22	0.311	-	-	-	0.290
23	0.226	-	-	-	-
24	0.322	-	-	-	-
25	0.408	-	-	-	-
Mean	0.317	0.242	0.289	0.331	0.356

exchangeable Ca content of these samples were also analyzed. It is seen that, the mean Ca content of the five blocks were 0.896, 1.015, 0.640, 0.989 and 0.877 meq 100 g^{-1} respectively with range as 0.565-1.303, 0.741-1.387, 0.534-0.866, 0.762-1.215 and 0.591-1.254 meq 100 g^{-1} (Table 3). Anju et al., (2020) reported an exchangeable Ca status of 0.364 and 1.85 meq 100 g^{-1} soil for the soils of AEU 3 and 9 respectively. As per Susan John et al., (2007), the exchangeable Ca status of the red loam soils (Oxisols) of Kerala was 0.49 meq 100 g^{-1} soil. The critical level of exchangeable Ca is fixed as 1.5 meq 100 g^{-1} (KAU, 2012). In all the five blocks, the status was low compared to the critical level which may be due to the leaching of cations especially K and Ca under high rainfall (Tisdale et al., 2003) conditions prevailing in this humid tropics.

Table 3. Exchangeable Ca status of the soils of the five Blocks of ICAR-CTCRI farm

Sample	Exchangeable Ca (meq 100 g^{-1} soil)				
No.	B I	B II	B III	B IV	B V
1	0.703	1.08	0.557	0.954	0.808
2	1.056	1.387	0.668	1.176	1.014
3	0.559	0.861	0.701	1.008	0.746
4	0.603	0.916	0.624	0.903	0.972
5	0.611	1.006	0.609	0.921	0.811
6	1.107	0.846	0.563	0.762	0.922
7	1.504	1.054	0.609	0.968	0.591
8	1.227	0.741	0.555	0.887	0.915
9	0.906	0.812	0.614	1.087	1.254
10	1.485	0.986	0.866	0.859	0.936
11	0.565	1.07	0.588	0.956	1.046
12	0.815	1.215	0.661	0.904	0.807
13	0.661	0.912	0.534	1.143	0.718
14	0.903	1.346	0.816	1.017	0.911
15	0.712	0.846	-	0.862	1.016
16	0.569	1.169	-	1.016	0.746
17	0.823	-	-	1.215	0.833
18	0.934	-	-	1.17	0.921
19	1.211	-	-	-	1.019
20	0.856	-	-	-	0.714
21	1.116	-	-	-	0.946
22	0.948	-	-	-	0.648
23	0.584	-	-	-	-
24	1.303	-	-	-	-
25	0.631	-	-	-	-
Mean	0.896	1.015	0.640	0.989	0.877

The mean available B and exchangeable Ca status of the five blocks of CTCRI farm is presented in Fig.2.

The correlation worked out between these two nutrients for the five blocks (Table 4) did not reveal any significant positive or negative correlation between these nutrients except for block V where it was significantly positive (r = 0.537) indicating some sort of synergism between these nutrients. These results corroborates to the findings of Rene et al., (2017), Sahin et al., (2015) and Palani and Indrani (2020) where they have reported synergistic interaction between Ca and B on yield, fertilizer use efficiency and quality attributes.

Sorption Study

The sorption study conducted by adding B solutions having concentrations ranging from 0.25 to 4.0 ppm and the extracted available B in soil solution after 3 days of incubation on soil dry weight basis is given in Table 5.

The data in Table 5 clearly indicated that, in all soils, there is a linear increase in the content of extracted B with increase in the concentration of B added. Susan

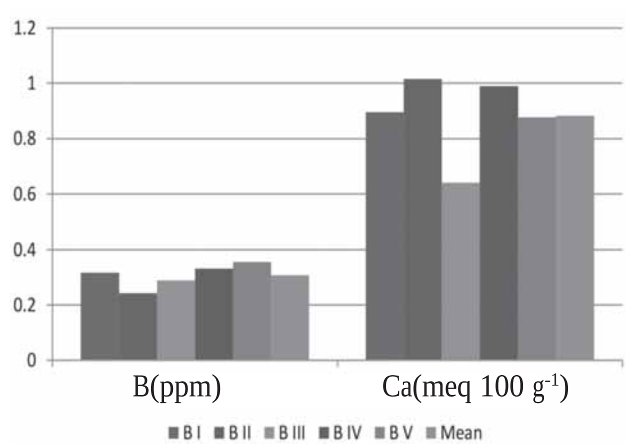

Fig.2. Mean available B and exchangeable Ca status of the five blocks of CTCRI farm

Table 4. Pearson correlation coefficient (r) computed between available B and exchangeable Ca for the soils of the five blocks of ICAR-CTCRI farm

Block	Correlation coefficient (r)
B I	-0.365
B II	-0.289
B III	0.254
B IV	-0.114
B V	0.537

Table 5. Extracted B in soils with varying B status by adding different concentrations of B

Soil B status (ppm)	Soil B extracted (ppm) under addition of B with varying concentrations				
	0.250	0.5	1.0	2.0	4.0
0.1	0.226	0.301	0.333	0.677	0.773
0.2	0.172	0.204	0.258	0.29	0.644
0.3	0.075	0.258	0.516	0.677	0.72
0.4	0.29	0.408	0.558	0.763	0.827
0.5	0.065	0.236	0.311	0.601	0.806
0.6	0.118	0.269	0.397	0.473	0.763
0.7	0.301	0.451	0.666	0.73	0.806
0.9	0.183	0.226	0.494	0.591	0.816
1.0	0.118	0.29	0.365	0.666	0.795

John et al., (2007) had undertaken similar studies in an Oxisol of Kerala and observed similar trend under the sorption study. The highest available extracted B was seen in soil with 0.4 ppm under application of 4 ppm B concentration (0.827 ppm). From 0.5 ppm onwards, there observed a decrease in B extracted at all levels of B added. Moreover, the B status of the soils did not influence much on the extracted B at all concentrations of B added. Among the different B status of soils, soil with 0.7 ppm B had the highest extracted B at 0.25, 0.5 and 1 ppm added B concentration. However, at 2 and 4 ppm added B concentration, 0.4 ppm soil B extracted the highest soil available B to the tune of 0.763 and 0.827 ppm respectively. The above trend observed can be justified as per the reports of Barrow (1989) that low pH, Nicholaichuk et al., (1988) that predominance of kaolinite clay with hydrous oxides of aluminium and iron and Mezuman and Keren (1981) that, reduction in moisture content on incubation substantially favoured the adsorption of B. This in turn resulted in subsequent decrease in plant available B in the soil solution though there is an increase in extracted B with increase in the level of added boron. The sorption curve fitted for the available B extracted with addition of different concentrations of B in soils of varying B status is depicted in Fig. 3.

As per the principles of Hunter's Systematic approach in fertilizer use (1984), from the sorption curve, the optimum dose of B was arrived as the quantity to be added, obtained from the X axis by drawing a line from 1.5 ppm (3 times the critical level of B) on the Y axis meeting the curves and from that point dropping a vertical line touching some point in the X axis. Since it is an extrapolated data and cannot expect much variation among the soils with varying B status, the statistical approach as described in the methodology viz., an inverse prediction function method available in the R package chemCal (chemical, CRAN - Package chemCal (r-project.org)) along with the calculation mentioned earlier was used. This predicted the optimum dose of B to be applied for soils with varying B status to attain soil B status equal to soil critical level of B (0.5 ppm), twice the critical level (1.0 ppm) and thrice the critical level (1.5 ppm). The results are presented in Table 6.

The table is a ready reckoner to apply B in soils having 0.1-1.0 ppm to attain critical level and above. It is a known fact that, the soils differ in their nutrient status including that of B and depending upon the soil and crop, the requirement of B will vary. That is why we have predicted for attaining up to thrice the critical level.

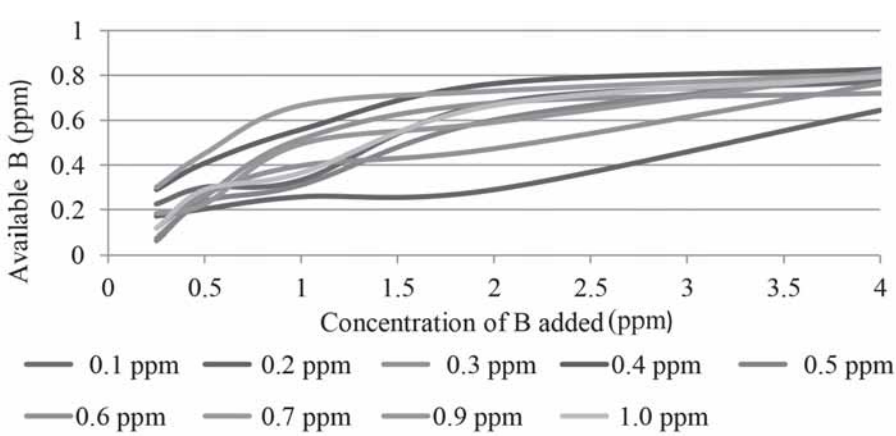

Fig.3. Sorption curve for soils of different B status

In normal case, B recommendations are usually made for soils having B less than its critical level as the range between deficiency and sufficiency of B is very narrow. The table clearly indicated that, the quantity of B to be applied increased with increase in the level to be attained either as twice or thrice the critical level over the critical level perse.

Table 6. Predicted values of B to be applied to attain different soil B contents

Soil B conc. (ppm)	Quantity of B (ppm) need to be added as per inverse prediction to attain		
	0.5 ppm	1.00 ppm	1.5 ppm
0.1	1.802	1.802	8.417
0.2	3.086	5.109	11.326
0.3	1.884	7.206	8.449
0.4	1.038	5.166	8.435
0.5	2.064	4.737	7.403
0.6	2.175	4.733	8.688
0.7	0.776	5.432	9.437
0.9	1.783	5.100	7.908
1.00	1.861	4.846	7.715
Range	0.78-3.09	1.80-7.21	7.4-11.33

The Table further reveals that, the highest amount of B to be applied for soils to attain critical level, twice the critical level and thrice the critical level is for soils with 0.2, 0.3 and 0.2 ppm respectively to the tune of 3.086, 7.206 and 11.326 ppm respectively (Table 6). The comparatively higher amounts of B predicted as per the inverse prediction function method in the present study to attain critical level and its different levels can be attributed to the peculiar soil physico-chemical properties of these soils where the properties mentioned above like pH, kaolinitic clay mineral as well as the reduction in moisture content had a significant role in adsorption resulting lowering of released B for plant uptake which in turn definitely might increase the quantity of B required to attain specific levels (Susan John et al., 2007). After this rate, with increase in soil B status, there observed a decline in the quantity of B to be applied in the case of critical level, twice and thrice the critical levels. The reason can be attributed to the different soil physico-chemical and biological properties contributing to the sorption and desorption of B which can result only random trends in making B available to soil.

Conclusion

The significance of B as an important micronutrient was depicted in recent times after observation of various types of nutritional disorders manifested in different crops due to its deficiency irrespective of the pH of the soil. Because of the influence of B on growth of the crop through its effect on xylem and phloem vessels as well as on productivity through its influence on pollen germination, it is beyond doubt that, B nutrition needs to be suitably addressed for its proper management under integrated nutrient management. In soils of Kerala, though the deficiency of B was known, it was properly documented during 2012, highlighting the need to take up research on this nutrient to avoid the existing crop failures due to this nutrient. In cassava and sweet potato, though severe tuber related issues affecting the marketability of tubers were observed, recently, very severe tuber destructive problems noticed for yams in the typical laterite (Typic Kandi Ustult) soils urged to take up research in this line. Hence, the above basic studies were conducted to know the status of B in a typical laterite soil by analysing reasonably good number of samples representing soils with different terrain as well as with and without crops. The study in turn could find the wide variation in the B status of the soils of the five blocks of CTCRI ranging from 0.1-1 ppm. Since the synergism between B and Ca was well known in the management of deficiency of both these nutrients, the exchangeable Ca content also was analysed. The correlation between these two nutrients for the five blocks could not establish any such strong relation either synergic or antagonistic. Though the intention of the sorption study was to arrive at the quantity of B to be applied to bring the status of B to its critical level of 0.5 ppm, in the present investigation, we have used an inverse prediction function method to predict the rate of B application in soils of varying B status to attain the critical level, twice and thrice the critical levels. Hence, it is informed that, one of the reasons for the occurrence of symptom in yams akin to the brown/hollow heart symptom of potato is due to the extremely low available B status coupled with low exchangeable soil Ca content. However, further elaborate studies need to be continued to see the influence of abiotic factors like heat and moisture stress in affecting the dynamics of these nutrients especially at different growth stages of the crop.

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