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Boron Content in Soils Dedicated to Coconut in the State of Guerrero, Mexico

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Abstract

Boron (B) is a micronutrient considered essential for coconut cultivation, but its content in tropical soils is often reported as very low, affecting the nutrition and productivity of several crops. Nowadays, the coconut in Latin America and other parts of the world is becoming a relevant issue due to the high number of families depending on its cultivation. However, the matter of soil fertility, where coconut is growing, needs more scientific attention. This is the case of B, which is suggested to be more important than any other micronutrient for high-quality crop yields, due to the little attention that has been given not only to soil fertility but also to the specific case of B. This study assessed the content of B in both soils and foliage of four Green Dwarf coconut plantations in the state of Guerrero, Mexico. One plantation (*Altos de Ventura*) was selected in the region of *Costa Chica* and three (*Aguas Blancas* 1, *Aguas Blancas* 2 and *Las Tunas*) in *Costa Grande.* Soil samples were taken at 0 - 30 cm and 30 - 60 cm deep and one composite foliar sample per each location. The average B contents in ppm, at 0 - 30 and 30 - 60 cm depth, were subjected to an Analysis of Variance (ANOVA), indicating highly significant differences (pr = 0.05) at 0 - 30 cm but not at 30 - 60 cm. Regardless of the statistical results, only *Aguas Blancas* 1 with 0.31 ppm and *Las Tunas* with 0.38 ppm showed to be in the sufficiency range suggested by Phytomonitor of 0.3 to 1.5 ppm. At 30 - 60 cm, all locations showed average B contents well below the critical levels. However, the B in leaves, of all plantations, were in the sufficiency range. Both the root proliferation into deeper underground and the accumulation of more B in lower soil layers due to leaching may explain this issue.

Subject Areas

Agricultural Engineering

Keywords

Deficiencies, Micronutrient, Soil Fertility, Leaching, Foliage

1. Introduction

Boron (B) has been relatively recently documented as an essential micronutrient for normal plant development and growth. However, the ranges in soil that could cause deficiencies and toxicities are narrower than those for any other essential element. Additionally, soil B content may be normal for a certain type of plant, but it may be toxic or deficient for another (Malavé-Acuña, 2005) [1].

Boron is at low levels in tropical soils, affecting the nutrition and productivity of several crops, including coconut palm. Considering the importance of *Coconut* in Latin America and other parts of the world, greater attention needs to be paid to soil fertility and crop nutrition as an issue that has received little attention. It is estimated that the critical level of available B is 1 ppm for calcareous soils, 0.8 ppm for clayey soils, 0.5 ppm for loamy soils and 0.3 ppm for sandy soils [2].

On the other hand, considering the importance of the coconut in the state of Guerrero, Mexico and that the current plantations are already very old and unproductive, there is a strategy to replace actual cultivars with new ones.

The renewal plan includes the selection of new and highly productive areas, including the assessment of the soil fertility and plant nutrition, including the forgotten B, whose deficiencies have been documented in other regions of the world, such as the state of Rio de Janeiro, Brazil (Pinho *et al.*, 2008) [3].

In Mexico, B deficiencies have been observed in some areas of the state of Quintana Roo and according to field experience, the deficiencies are being noticed more frequently (**Figure 1**). According to Alarcón Vera (2001) [2], the cells divide but the separation is not carried out correctly, resulting in an incomplete and irregular development of leaves that appear distorted and there is a lack of elongation of internodes.

Figure 1. B deficiency in a coconut plantation in southern Quintana Roo, Mexico. Photograph taken by Matilde Cortazar Rios, Principal Coconut Researcher in the Chetumal Experimental Station of INIFAP, state of Quintana Roo, Mexico.

Due to the foregoing, this work aimed to assess the content of B in both soils and plants of coconut in the main regions of Guerrero, Mexico.

2. Materials

Sampled Sites, Regions and Municipalities

The study was carried out in the state of Guerrero, Mexico in the regions of Costa Chica and Costa Grande in a warm sub-humid climate Aw0 and average annual rainfall of 1200 mm. Four locations were selected (Figure 2): one location (*Altos de Ventura*) in Costa Chica and three locations (*Aguas Blancas* 1, *Aguas Blancas* 2 and *Las Tunas*) in Costa Grande, all scattered between 16˚42'45" to 17˚05'51" North Latitude and −99˚13'08" to −100˚28'58" West Longitude.

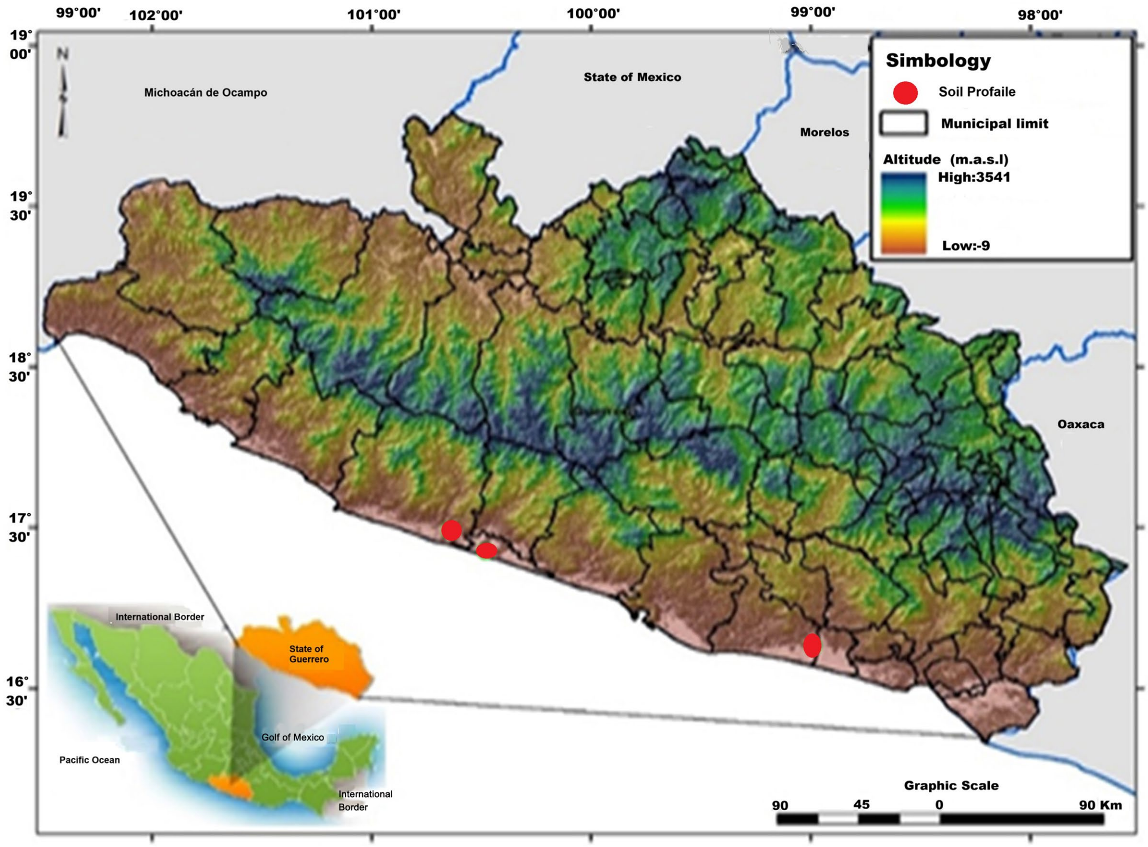

Figure 2. Geographic location of the sampled sites.

Altos de Ventura was located in the Municipality of San Marcos, *Aguas Blancas* 1 *and Aguas Blancas* 2 in the Municipality of Tecpán de Galeana, whilst *Las Tunas* in Benito Juarez.

3. Methods

3.1. Soil Sampling Method

Using a Random Systematic Two-Dimensional Method (RSTDM), individual soil samples, per each hectare, were taken at 0 - 30 and 30 - 60 cm depths at a distance of one meter from the trunk. It is reported that 7 to 20 sub-samples per 5 to 10 hectares are appropriate for homogeneous surfaces. Figure 3 shows an example of 10 hectares where nine individual samples were taken.

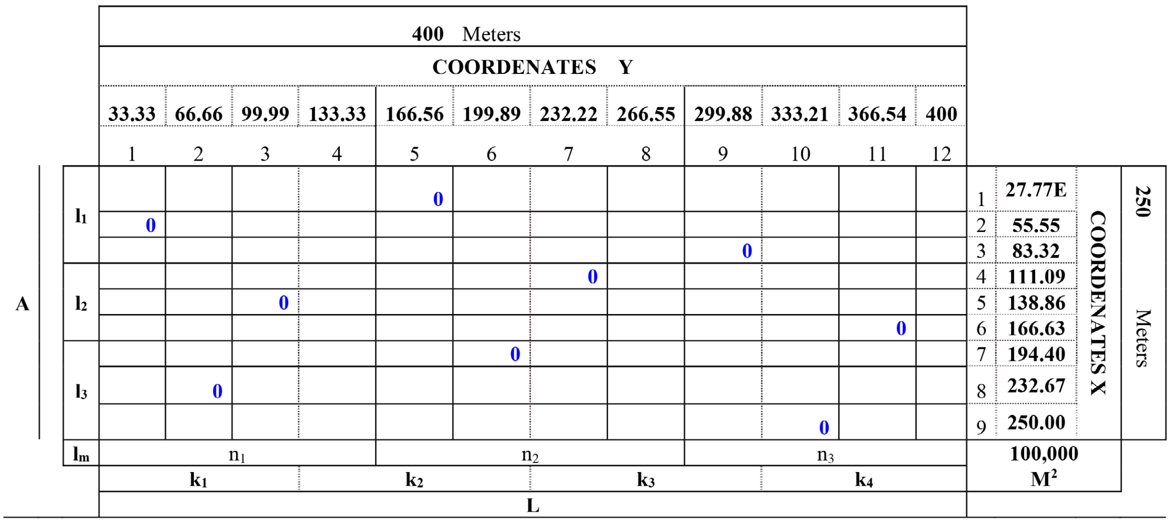

Figure 3. Diagram showing an example of soil sampling on 10 hectares using the RSTDM.

Nine samples were taken in each of the localities of *Altos de Ventura* and *Las Tunas*, while seven (7 hectares) and five (5 hectares) individual samples were taken in *Aguas Blancas* 1 and *Aguas Blancas* 2, respectively.

3.2. Chemical Analysis for Boron

Soil samples were sent to Phytomonitor Laboratory, where boron (B^{+3}) content was determined using Azomethine-H as reagent and reported in parts per million (ppm). A number of well-known methods use specific reagents for color development, which are measured at a characteristic wavelength. The method using Azomethine-H, as a chromogenic reagent, is the most commonly used spectrophotometric method for determining B in soil analysis [1].

3.3. Statistical Analysis

The results were subjected to a Simple Analysis of Variance ($p = 0.05$) using Stat-Graphic Advisor Software, comparing means with Fisher's test. Taking into account that the four locations were agronomically different from each other, they were considered as already pre-established TREATMENTS in the field. The individual sample points taken on each location were qualified as REPLICATIONS. So, two analyses of Variance (ANOVA) were taken into account, one per each depth (0 - 30 and 30 - 60 cm).

3.4. Critical Levels of Boron in Soils

B contents (ppm) were compared with the sufficiency ranges (0.3 - 1.5 ppm) documented by Phytomonitor (2015) [4] as well as other critical levels reported [2] such as: 0.8 ppm for *Clayey* soil, 0.5 ppm for *Loamy* soils and 0.3 ppm for *Sandy* ones. The last two *Loamy* and *Sandy* soils are representative ones of the soils under study.

3.5. Foliar Sampling Method and Critical Levels (CL)

Foliar composite samples formed by three subsamples were taken from each coconut plantation, considering the central part of leave number 9. Each subsample consisted of three central 20 cm long leaflets to make the composite sample. One composite sample was taken in Altos de Ventura, two in each *Aguas Blancas* 1 and *Aguas Blancas* 2 and three in *Las Tunas*.

The B content in leaves was reported in parts per million (ppm) by the Mexican Phytomonitor Laboratory [4], which suggests 5.0 - 25.0 ppm as the CL. Other authors consider 10 - 75 ppm to many crops (Arunkumar *et al.*, 2018) [5], but Sobral (1998) [6], specifically for *coconut*, suggested 10 ppm, which is in the range of the foregoing values. Jeena Mathew *et al.* (2018) [7] found 0.48 ppm and 13.27 ppm as CL for soil and leaves of coconut palms in Kerala, India after standardizing the CL of B. On the other hand, Moura *et al.* (2013) [8] found 23.5 ppm as the CL in leaves of coconut palms.

On the other hand, CL of other tropical crops have been documented [2], indicating: 30 - 60 ppm for Cassava, 30 - 100 ppm for Mango, 20 - 50 ppm for Papaya and 25 - 60 ppm for Litchi.

4. Results

4.1. Boron Contents (ppm) in Soils at 0 - 30 and 30 - 60 cm Depth

4.1.1. Altos de Ventura

Figure 4 shows the B contents at 0 - 30 and 30 - 60 cm depths in Altos de Ventura. The chemical heterogeneity of the soil is evident, with a minimum content of 0.03 ppm, a maximum of 0.38 ppm, and an average of 0.17 ppm, while at 30 - 60 cm the minimum was 0.04 ppm, the maximum 0.55 ppm, and the average 0.20 ppm. Both averages are well below the lower critical limit of 0.3 ppm suggested by Phytomonitor (2015) [4], which is the lowest limit as compared to the other LC reported.

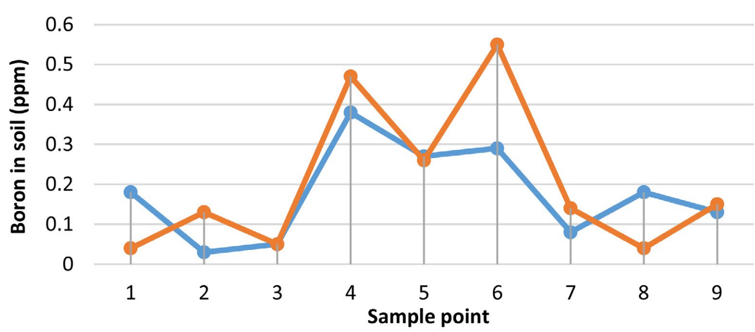

Figure 4. B content at two soil depths (0 - 30 cm, 30 - 60 cm) in Altos de Ventura, in the Municipality of San Marcos.

4.1.2. Aguas Blancas 1

In the case of Aguas Blancas 1 (Figure 5), the B content at 0 - 30 cm depth was higher than in Altos de Ventura, with an average of 0.31 ppm and a minimum and maximum value of 0.03 and 0.53 ppm, respectively. At that depth, the average B content is at the minimum value of the sufficiency range. However, at 30 - 60 cm, the average was 0.16 ppm. This suggests that in Aguas Blancas 1, there is a high probability that the coconut palm will show symptoms of B deficiency when the coconut roots grow deeper into the soil. However, the foliar analysis needs to be reviewed before giving an agronomic opinion.

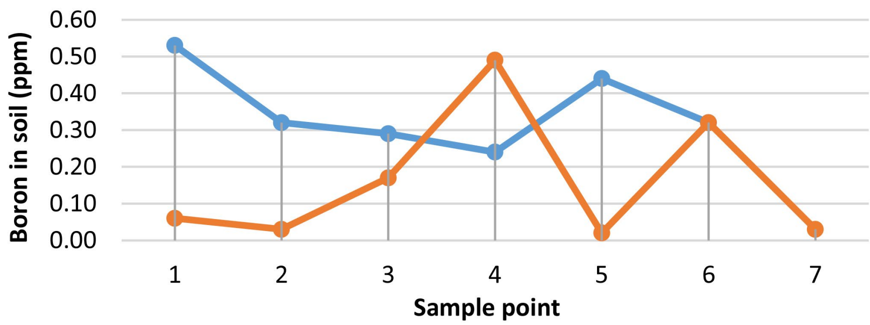

Figure 5. B content at two soil depths (0 - 30 cm, 30 - 60 cm) in Aguas Blancas 1 in the Municipality of Tecpán de Galeana, Costa Grande, Guerrero.

4.1.3. Aguas Blancas 2

On the other hand, in Aguas Blancas 2 (Figure 6), very low averages of B are observed at both depths, with 0.19 and 0.15 ppm at 0 - 30 and 30 - 60 cm, respectively. The highest content, 0.32 ppm, was found at only one sampling point at both depths. This location presents very severe B limitations, and deficiencies of this element are expected to be found in new plantations in the short and medium term.

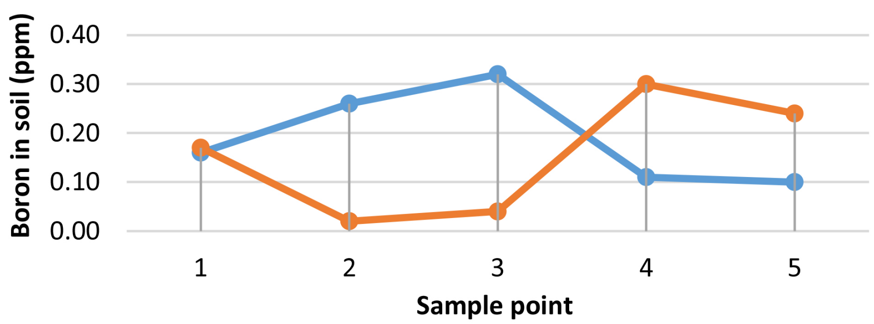

Figure 6. B content at two soil depths (0 - 30 cm, 30 - 60 cm) in Aguas Blancas 2 in the Municipality of Tecpán de Galeana, Costa Grande, Guerrero.

4.1.4. Las Tunas

In regard to B content in Las Tunas (Figure 7), the highest concentration of this element (0.64 ppm) was observed at sampling point number 1 at a depth of 0 - 30 cm, as compared to the other locations.

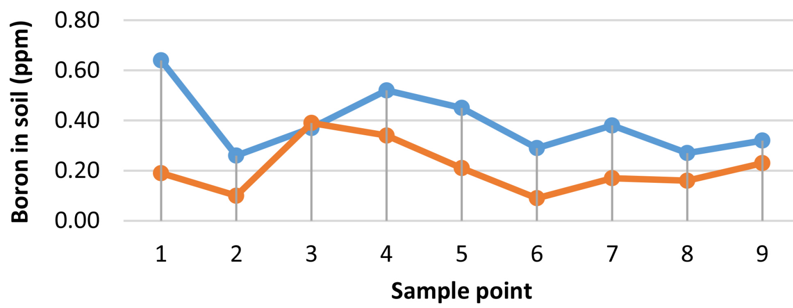

Figure 7. B content at two soil depths (0 - 30 cm, 30 - 60 cm) in Las Tunas in the Municipality of Benito Juarez Costa Grande, Guerrero.

5. Statistical Analysis (ANOVA and Fisher's Test) for Average B Content in Soils of Four Coconut Plantations

Table 1 shows the results of the ANOVA for 0 - 30 cm and 30 - 60 cm depths. Highly significant differences (0.05 probability) are observed at 0 - 30 cm depth but not at 30 - 60 cm.

Table 1. Analysis of variance (ANOVA) for B content in soils (ppm) of four coconut plantations at 0 - 30 and 30 - 60 cm depth in Guerrero, Mexico.

Treatments	Square Sum (SS)	Degree of Freedom (DF)	Mean Square (MS)	F	p
Plantations (0 - 30 cm)	0.248	3	0.082	5.03	0.0070 (*SD*)
Plantations (30 - 60)	0.017	3	0.005	0.24	0.8674 (*SE*)

SD = Statistically Different; SE = Statistically Equal.

Table 2 shows three statistically distinct groups at 0 - 30 cm according to the average values found in each coconut plantation according to Fisher's least significant difference (LSD) procedure, suggesting that there are no statistically significant differences between any pair of means at the 95.0% confidence level. Homogeneous group has been identified based on the alignment of the same letter (A, B and C in the column). There are no statistically significant differences between levels that share the same letter. Altos de Ventura had the lowest average value (0.17 ppm) of Boron, sharing the same letter A with Aguas Blancas 2 (0.19 ppm). At the same time, Aguas Blancas 2 shares the same B letter with Aguas Blancas 1 and Aguas Blancas 1 shares the same letter C with Las Tunas, which had the highest average Boron content with 0.30 ppm.

On the other hand, Table 3 shows the results of Fisher's least significant difference (LSD) procedure at 30 - 60 cm depth. No statistically significant differences were found between any pair of means at the 95.0% confidence level. Homogeneous group has been identified based on the alignment of the same letter. In this case, the alignment was only with letter A.

Table 2. Comparison of means of B (ppm) at 0 - 30 cm depth in soils of four coconut plantations in the state of Guerrero, Mexico (Treatments with the same letter are statistically equal).

Treatments	Sampled Points (N˚)	Average B (ppm)	Homogeneous Groups
Altos de Ventura (0 - 30 cm)	9	0.17	A
Aguas Blancas 2 (0 - 30 cm)	5	0.19	AB
Aguas Blancas 1 (0 - 30 cm)	7	0.31	BC
Las Tunas (0 - 30 cm)	9	0.30	C

Table 3. Comparison of means of B (ppm) at 30 - 60 cm depth in four coconut plantations in the state of Guerrero, Mexico (Treatments with the same letter are statistically equal).

Treatments	Sampled Points (N˚)	Average B (ppm)	Homogeneous Groups
Altos de Ventura 30 - 60 cm)	9	0.20	A
Aguas Blancas 2 (30 - 60 cm)	5	0.15	A
Aguas Blancas 1 (30 - 60 cm)	7	0.16	A
Las Tunas (30 - 60 cm)	9	0.20	A

6. Foliar B Contents in Four Coconut Plantations in Guerrero Mexico

The critical levels of B in leaves have been suggested by different authors, such as the Mexican Phytomonitor Laboratory [4], which pointed out a range between 5.0 to 25.0 ppm while other authors consider 10 [6] and 23.5 [8], ppm as CL. Most recently, Saldanha *et al.* (2017) [9] reported 15 ppm as the CL in a hybrid coconut in Brazil. According to Arunkumar *et al.* (2018) [5], citing Benton (2003), the adequate B levels in dried leaf tissues in many crops range from 10 to 75 mg·kg^{-1} (ppm). However, the requirements depend on whether it is a Monocotyledonean plant (1 - 6 ppm) or a Dicotyledonean one 20 - 70 ppm).

Table 4 shows the B contents in leaves of four Coconut plantations. It seems that any coconut palm has B deficiencies if we consider the reference values given by the authors already mentioned. All specific samples ranged from the minimum 33 ppm to the maximum 54 ppm, all of them in Las Tunas. The average B values ranged from 40 to 48 ppm in Aguas Blancas 1 and Altos de Ventura, respectively. The averages were all above the Critical Limits.

Table 4. B contents in leaves sampled in four Coconut plantations in Guerrero, Mexico.

Treatments	Foliar B (ppm)			Average Foliar B
	Sample 1	Sample 2	Sample 3	
Altos de Ventura	48			48
Aguas Blancas 2	51	35		43
Aguas Blancas 1	47	34		40
Las Tunas	33	36	54	41

7. Discussion

Boron, one of the micronutrients frequently found at low levels in tropical soils, affects the nutrition and productivity of coconut palms in tropical climates. Moura *et al.* (2013) [8] found, in a yellow-red Latosol with a B content in the soil of 0.18 mg·dm^{-3}, that the highest coconut production of Green Dwarf Variety was associated with levels of 0.6 mg·dm^{-3} (ppm) of B in the soil and 23.5 mg·kg^{-1} (ppm) in the leaves. Ninety-five percent of maximum palm production was obtained with a boron dose of 2.1 kg·ha^{-1}.

As shown in **Table 5**, soil B deficiencies are present in all coconut plantations in different percentages when B, in each sampled point, is taken into consideration. The heterogeneity values were graphed in **Figures 4-7**. However, when comparing the values of B contents in the leaves of the same locations (**Table 4**), any coconut palm showed B deficiencies. It means that there are other factors that favor the uptake of the low available B by the coconut palms. This could be explained by the exploration of roots into the underground, deeper than the limit of 60 cm, where samples were taken in this work.

Table 5. Sufficiency (green color) and deficiency (red color) levels of B at specific soil points sampled at two depths (0 - 30 cm and 30 - 60 cm) in four coconut plantations in Guerrero, Mexico.

Location (Treatments)	1	2	3	4	5	6	7	8	9	Sampled Points with B Deficiencies (%)
Alto de Ventura (0 - 30 cm)	0.18	0.03	0.05	0.38	0.27	0.29	0.08	0.18	0.13	88.8
Alto de Ventura (30 - 60 cm)	0.04	0.13	0.05	0.47	0.26	0.55	0.14	0.04	0.15	77.7
Aguas Blancas-1 (0 - 30 cm)	0.53	0.32	0.29	0.24	0.44	0.32	0.03			42.8
Aguas Blancas-1 (30 - 60 cm)	0.06	0.03	0.17	0.49	0.02	0.32	0.03			71.4
Aguas Blancas-2 (0 - 30 cm)	0.16	0.26	0.32	0.11	0.1					80.0

Continued

Aguas Blancas-2 (30 - 60 cm)	0.17	0.02	0.04	0.30	0.24					80.0
Las Tunas (0 - 30 cm)	0.64	0.26	0.37	0.52	0.45	0.29	0.38	0.27	0.32	33.3
Las Tunas (30 - 60 cm)	0.19	0.1	0.39	0.34	0.21	0.09	0.17	0.16	0.23	77.7

Table 6 and Table 7 show the B contents in the soil, deeper than 60 cm. As in the case of Altos de Ventura (Table 6), the soil profile shows B deficiencies aboveground in the first horizon (0 - 16 cm) with 0.29 ppm but no deficiencies were found underground: 16 - 38 cm (0.38 ppm), 38 - 86 cm (1.18 ppm) and 86 - 110 cm (0.85 ppm) higher in about 180% as compared to the Critical Limit (CL) of 0.3 ppm. Sandy soils have less B than clayey soils. In sandy soils, such as those soils sampled in this study, B is easily leached until it accumulates in the lower soil layers, as mentioned by Alarcón Vera (2001) [2].

Table 6. B levels at different depths (cm) of horizons into the soil profile of coconut plantations in Altos de Ventura Guerrero, Mexico (Red color = deficiency and Green color = sufficiency).

Horizon	Depth (cm)	Texture	pH	B + 3
H1	0 - 16	Loamy	7.39	0.29
H2	16 - 38	Loamy	8.66	0.38
H3	38 - 86	Sandy Loam	8.80	1.18
H4	86 - 110	Sandy Loam	8.48	0.85

Table 7. B levels at different depths (cm) of horizons into the soil profile of coconut plantations in Las Tunas Guerrero, Mexico (Red color = deficiency and Green color = sufficiency).

HORIZON	DEPTH (cm)	TEXTURE	pH	B + 3
H1	0 - 30	Sandy Loam	6.84	0.29
H2	30 - 52	Sandy Loam	7.07	0.48
H3	52 - 92	Sandy Loam	7.06	0.32
H4	92 - 116	Sandy Loam	7.92	0.40

In Las Tunas (Table 7), the B content is slightly lower than the CL at 0 - 30 cm (0.29 ppm) than the CL but higher in the deeper horizons: 30 - 52 cm (0.48 ppm), 52 - 92 cm (0.32 ppm) and 92 - 116 cm (0.40 ppm). In Figure 8 and Figure 9, two soil profiles of Altos de Ventura and Las Tunas are represented with different horizons deeper than 1 meter underground.

Figure 8. Soil profile in Altos de Ventura.

Figure 9. Soil profile in Las Tunas.

8. Conclusions

Nowadays, the coconut in the tropical world is becoming a highly relevant crop due to the high number of families depending on its cultivation. However, the matter of soil fertility, where coconut is growing, needs more scientific attention. Due to the fact that B is suggested to be more important for coconut than any other micronutrient for high-quality crop yields, this work aimed to assess the content of B in both soils and foliage of four coconut plantations in the state of Guerrero, Mexico and its relationship with the Critical Levels (CL) reported by the Literature. The main findings were the following:

1) B contents at 0 - 30 cm depth are statistically different among locations, but statistically equal at 30 - 60 cm.

2) Regardless of the statistical results, at 0 - 30 cm, only Aguas Blancas 1 with 0.31 ppm and Las Tunas with 0.38 ppm showed to be in the sufficiency range suggested by Phytomonitor of 0.3 to 1.5 ppm. At 30 - 60 cm, all locations showed average B contents well below the critical level.

3) In contrast to the low B contents in the soil, all plantations showed sufficient B contents in the foliage. This could be explained by the exploration of roots into the underground, deeper than the limit of 60 cm, where samples were taken in this work.

4) B is easily leached in sandy soils, like those soils sampled in this work. Even though B was a missing element in the soil, no deficiencies were shown in the plant. Both the root proliferation into deeper underground and the accumulation of more B in lower soil layers can explain this issue.

5) In this study, no calibrations of B extraction methods of chemical analysis were performed due to the fact that it was just a general diagnosis, so calibrations and correlations would be a compulsory recommendation for future scientific research.

6) It is important for farmers to continually perform soil and plant analyses in order to make a rational use of organic, inorganic fertilizers and cover green legumes in order to avoid the indiscriminate use of fertilizers.

Acknowledgements

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Conflicts of Interest

The authors declare no conflicts of interest.

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