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Macronutrient Analysis of Soil and Leaf for Diagnosing the Nutritional Condition of Different Coconut (*Cocos nucifera* L.) Cultivars in Quintana Roo, Mexico

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Abstract

In Mexico, various strategic programs and technological management packages have been implemented to promote the coconut value chain. Those strategies are related to the introduction of new promising coconut germplasm. However, a successful genetic program is only possible if the nutritional conditions of the materials are properly known to support a fertilization strategy. The objective of this work was to diagnose the nutritional condition of soils and plants of different Coconut (*Cocos nucifera* L.) cultivars in Quintana Roo, Mexico. Six cultivars were studied in three locations: **Xul-ha** with *Creole Colima Tall* from the Mexican Pacific, **Bacalar 1**: with the *Tagnanan Hybrid* from Philippines, **Bacalar 2-INIFAP** with four ecotypes: *Rotuma Tall* (Fiji Oceania), *Markham Valley Tall* (Papua Nueva Guinea), *Creole Michoacan Tall* (Mexican Pacific) and *Malayan Yellow Dwarf* (Malaysia). Soil and foliar samples were taken and analyzed for Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg). The content of N and P in all six cultivars were below the optimal level. It is assumed that N and P deficiencies are related to low N and P contents in the soils. P deficiencies were found in all cultivars due to its low soil availability. At high pH values, the available form ($H_2PO_4^-$) can precipitate by reacting with calcium (Ca^{2+}) or magnesium (Mg^{2+}) to form slightly soluble phosphates. All soils showed K contents in excess but the "*Tagnanan Hybrid*" of **Bacalar 1** showed deficiencies; may be related to the extremely high Mg. The Ca in leaves of the six cultivars were above the optimal level as consequence of its very high concentration in the soils. Even though, all soils had Mg levels ranging from optimal to excess, five of the six cultivars showed Mg deficiencies, excepting the "*Tagnanan Hybrid*" of **Bacalar 1** with the highest excess levels of Mg in the soil.

Subject Areas

Agricultural Engineering

Keywords

Nutrimental Conditions, Nutrient Availability, Optimal Fertilization, Macronutrient, Diagnosing

1. Introduction

The coconut palm is considered one of the most important tropical crops in approximately 90 countries. According to the latest statistics, the world estimated production is 68 million nuts in an area of 12.08 million ha, where 70% of the total area and production is concentrated in India, Indonesia, and Philippines [1] [2].

In recent years, the coconut has grown commercially at a very rapid rate throughout the world due to various high-value products such as packaged coconut water, coconut milk products, virgin coconut oil and derivatives, fiber derived products for the automotive industry and coconut-biodiesel [3] [4]. Is the livelihood of approximately 11 million producers around the world and contributes significantly for food security, improving nutrition, employment, and income generation [5].

In Mexico, the value of national production in 2017 was 2061 million pesos and recently it increased to 2019, 2652 million pesos. At least ten states depend on coconut production, Guerrero being the main producer state (193,490 $t \cdot year^{-1}$). There are approximately 80,000 hectares planted which depend on approximately 30,000 producers [6] [7].

The main problems facing are: 1) low production due mainly to old age palms and low soil fertility, 2) diseases, where lethal yellowing (LYD) stands out, 3) pests, such as the black palm weevil (*Rhynchophorus palmarum*) and 4) climate change [8] [9] [10].

In Mexico, various strategic programs and technological management packages have been implemented to promote the coconut value chain. Those strategies are related to the improvement of yields by introducing better and more productive germplasm using the correct agronomic management of the crop such as: the propagation of new material (resistant to AL and highly productive), substrate, plantation framework, water requirements, optimal use of the soil and mineral fertilization programs [11] [12] [13].

In 2011 new promising coconut germplasm, in the form of embryos, were introduced to Mexico from the Germplasm Bank of the Centre National de Recherche Agronomique "Mark Delorme" of Ivory Coast Africa to be firstly reproduced *in vitro* and then to evaluate their agro-climatic, adaptation and potential productivity in the edaphic conditions of Quintana Roo Mexico. However, a successful genetic program is only possible if the nutritional conditions of the materials are properly known in order to support a strategic rational fertilization program. In this regard, Mahindapala, (1981) [14] comments that to carry out a fertilization program, is essential to have in-depth knowledge of crop nutrition for optimal application doses.

In fact, there are several studies related to the positive response of coconut production when applying fertilizers. By instance, in 2008, it was proved that the number of female flowers, fruit, fruit weight, coconut water volume and total soluble solids in a Dwarf Coconut from Brazil increased substantially with the application of 2.10 kg N and 3.50 kg K per plant and year. [15]. The main objective of this work was to diagnose the nutritional condition of soils and plants of different Coconut (*Cocos nucifera* L.) cultivars, introduced from abroad, in Quintana Roo, Mexico.

2. Materials and Methods

2.1. Selection and Location of Evaluated Plantations

This study was carried out in three locations of the south region of the state of Quintana Roo, Mexico with a warm sub-humid tropical climate (Aw1). The three locations were selected as follow:

1) Xul-ha: plantation with the *Creole Colima Tall* from the Mexican Pacific of 4 years old located in the Juan Sarabia village of Xul-ha, municipality of Othon P. Blanco in the coordinates N (18˚36'48.2") and W (88˚27'17.0").

2) Bacalar 1: plantation with the *Tagnanan Hybrid* ecotype (breeding from *Malayan Yellow Dwarf* and Tagnanan Tall from Philippines) 4 years old located in the Municipality of Bacalar at coordinates N (18˚49'22.99") and W (88˚17'57.86").

3) Bacalar 2-INIFAP: plantation with four ecotypes: *Rotuma Tall* (Fiji Oceania), *Markham Valley Tall* (Papua Nueva Guinea), *Creole Michoacan Tall* (Mexican Pacific) and *Malayan Yellow Dwarf* (Malaysia), all of four years old after transplantation, located in the INIFAP San Felipe Bacalar Experimental Station located at Latitude: 18.6783 N and Longitude: −88.3924 W.

2.2. Soil Sampling and Chemical Analysis

A chemical soil analysis measures the nutritional levels in the soil. It is a diagnostic and guidance tool to reinforce information on soil characterization, productivity potential, and crop management. It is important to measure the sufficiency, deficiency or toxicity of elements as well as excessive acidity and salinity. In our case, a composite soil sample at 20 cm deep, formed by three subsamples from the same number of genotypes was taken below the palm canopy where more feeder roots are growing (**Figure 1**).

The chemical parameters and their method of analysis were the next: pH (1:1 H_2O), Nitrogen-NO_3 (N) (Brusina Method), Phosphate Phosphorus P-PO_4^- (P) (Bray Method) and the Exchangeable Cations Potassium (K^+), Calcium (Ca^{2+}), and Magnesium (Mg^{2+}) using Ammonium Acetate (NH_4^+ CH_3COO pH 7.0) to displace them from soil colloids and quantified by atomic absorption. Soil reference critical levels, for comparison purposes, were taken from the Official Mexican Standard that establishes specifications for fertility, salinity, and soil classification, studies, sampling, and analysis suggested by SEMARNAT, (2002) [16].

2.3. Foliar Sampling

For foliar sampling, a composite sample formed by three subsamples from the same number of materials was taken considering the central part of leave number 9 (**Figure 2**). Each subsample consisted of three central 20 cm long leaflets (**Figure 3**) to make the composite sample. Chemical foliar analysis for N, P, K, Ca, and Mg was reported in percentage (%) by the Mexican Phytomonitor laboratory [17]. The critical levels were those suggested by Sobral, 1998 and Magat, 1991 [18] [19] as reference values for different coconut cultivars.

Figure 1. Soil sampling at 0 - 20 cm deep showing high Calcium Carbonate ($CaCO_3$).

Figure 2. Foliar sampling in middle of leave 9.

Figure 3. 20 cm long leaflets after cutting.

3. Results and Discussion

3.1. Soil Fertility Values of Agroecosystems Studied and Reference for Optimal Chemical Conditions

In Table 1 are described the soil chemical attributes of the three localities. Those attributes were obtained from the chemical analysis of composite soil samples made from mixing three individual subsamples, taken at 0 - 20 cm deep in the soil below the genotypes' canopies.

In **Xul-ha** the soils have a moderately alkaline pH (7.6) with $N\text{-}NO_3$ (12.80 ppm) and available P deficiencies (2.0 ppm). There was an excess of K^+ (870 ppm), Ca^{2+} (11,000 ppm), and Mg^{2+} (420 ppm).

In **Bacalar 1** with the *Tagnanan hybrid*, the soils have a moderately alkaline pH of 7.95 higher than the other soils and again $N\text{-}NO_3$ (17.60 ppm) and P deficiencies (2.0 ppm) and excess of K^+ (830 ppm), Ca^{2+} (8800 ppm), and Mg^{2+} (1130 ppm).

In **Bacalar 2-INIFAP** located in San Felipe Bacalar Experimental Site the soils are of moderate pH (7.8), optimal amounts of $N\text{-}NO_3$ (20.2 ppm), very high P deficiencies (2.1 ppm), excess of K^+ (540 ppm) and Ca^{2+} (6000 ppm), and optimal Mg^{2+} content (163 ppm).

The most outstanding findings are the very low contents of P and the excess of Ca which is highly related to calcareous origin soils and high pH's as those of the state of Quintana Roo in the Yucatán Peninsula of Mexico. It has been documented that P fixation in the soil was recognized in Europe since 1850 and in the United States since 1900 according to Sanguino Soto (1961) [20].

Different studies have been carried out in order to substantiate the chemical bases of P fixation. Soil-bound P is insoluble to a certain extent. Compounds of low solubility are formed in both acidic and alkaline soils. Roots take up phosphorus mainly in the form of primary orthophosphate ion ($H_2PO_4^-$), or as secondary orthophosphate ($H_2PO_4^-$). The pH greatly influences the amount in which these ions are absorbed by the plant. At high pH values, $H_2PO_4^-$ can precipitate by reacting with calcium (Ca^{2+}) or magnesium (Mg^{2+}) and forming slightly soluble phosphates [21] such as tricalcium phosphate: $Ca_3(PO_4)_2$.

Table 1. Chemical attributes of selected coconut plantations: Xul-ha, Bacalar 1 and Bacalar 2-INIFAP.

Location	pH (1:1 H_2O)	Soil attributes				
		$N\text{-}NO_3$	$P\text{-}PO_4$	K^+	Ca^{2+}	Mg^{2+}
		(ppm)				
Xul-ha	**7.60**	**12.80**	**2.00**	**870**	**11,600**	**490**
Bacalar 1	**7.95**	**17.60**	**2.00**	**830**	**8800**	**1130**
Bacalar 2-INIFAP	**7.86**	**20.20**	**2.10**	**540**	**6000**	**163**
Reference from Official Mexican Norm	**6.60 - 7.30**	**20 - 40**	**15 - 30**	**117 - 234**	**1000 - 2000**	**156 - 360**

Deficient sufficient excess.

In the case of K it is observed (**Table 1**) that all locations have contents above the sufficiency range of 117 to 234 ppm with values ranging from 540 ppm (Bacalar 2-INIFAP) to 870 ppm (Xul-Ha), two times more than those reported as reference optimal values by the Official Mexican Norm [16]. Doll and Lucas (1973) [22] comment that, in general, crops do not respond to the application of K when the exchangeable amount of the element is greater than 0.21 meq/100gr (82 ppm) in sandy and sandy loam soils and 0.32 meq/100gr (124.8 ppm) in loamy and clayey soils.

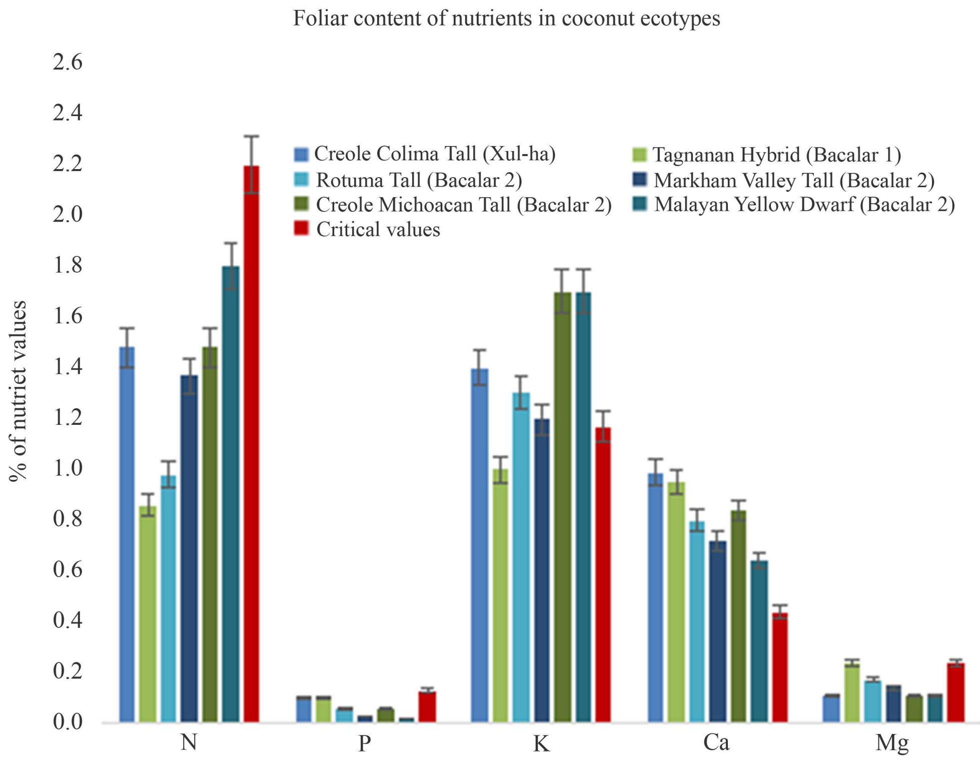
3.2. Foliar Nitrogen (N) Content (%)

Foliar analysis in *Creole Colima Tall* showed Nitrogen deficiencies (1.48%) (**Figure 3**), which can be related to N deficiencies in the soil of **Xul-ha**. In Thailand, standard range for optimum foliar N is 1.8% to 2.0% for tall, dwarf, and hybrid coconuts. However, several healthy, high-yielding Thai-type Nam Hom coconut trees have leaf N below 1.8%, classified as N deficient according to the existing standard [23]. Therefore, it is important to review the nutritional status of plant, relating the macronutrient content of both plant and soil.

In the case of the *Tagnanan Hybrid*, the analysis showed values of 0.86%, representing only 40% of the critical value (2.2%). Even though, the **Bacalar-1** soils have higher N content (17.60 ppm) than **XuL-ha** (**Table 1**) the *Tagnanan Hybrid* could be a highly requiring N genotype and/or a material of low root absorption capacity.

In the case of **Bacalar 2-INIFAP**, where four materials are planted, and soil N is in sufficiency levels (20.20 ppm) the *Rotuma Tall* showed outstanding deficiencies with lower values of 0.98% than the other three ecotypes studied, 1.37% for *Markham Valley Tall*, 1.48% for *Creole Michoacan Tall*, and 1.8% for *Malayan Yellow Dwarf* (**Figure 4**).

This contrasting behavior can be attributed to a differential capacity to extract N from the soil, or an enrichment Nitrogen-fixing bacteria in the coconut



	N	P	K	Ca	Mg
Creole Colima Tall (Xul-ha)	1.48	0.1	1.4	0.99	0.11
Tagnanan Hybrid (Bacalar 1)	0.86	0.1	1	0.95	0.24
Rotuma Tall (Bacalar 2)	0.98	0.06	1.3	0.8	0.17
Markham Valley Tall (Bacalar 2)	1.37	0.03	1.2	0.72	0.14
Creole Michoacan Tall (Bacalar 2)	1.48	0.06	1.7	0.84	0.11
Malayan Yellow Dwarf (Bacalar 2)	1.8	0.02	1.7	0.64	0.11
Critical values	2.2	0.13	1.17	0.44	0.24

Figure 4. Foliar Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg) content in leaves of *Creole Colima Tall* (Xul-ha), *Tagnanan Hybrid* (Bacalar 1), *Rotuma* Tal (Bacalar 2-INIFAP), *Markham Valley Tall* (Bacalar 2-INIFAP), *Creole Michoacan Tall* (Bacalar 2-INIFAP) and *Malayan Yellow Dwarf* (Bacalar 2-INIFAP).

rhizosphere, which are responsible for transforming atmospheric N into available forms in a symbiotic way. The microorganisms can solubilize phosphates, and can even reduce the incidence of plant diseases in the root zone [10]. Therefore, it is compulsory to analyze the specific role of these improved microorganisms in different coconut ecotypes.

3.3. Foliar Phosphorus (P) Content (%)

The foliar analysis of both *Creole Colima Tall* and *Tagnanan Hybrid* showed a phosphorus content slightly below the critical limit with 0.1% (Figure 4). This is attributed to the extremely low phosphorus content in the soil (Table 1).

The foliar analysis of the four coconut palm ecotypes in **Bacalar 1-INIFAP** indicated very high P deficiencies, 70% below the optimal limit, with 0.06%, 0.03%, 0.06% and 0.02% for *Rotuma Tall*, *Markham Valley Tall*, *Creole Michoacan Tall* and *Malayan Yellow Dwarf* respectively (Figure 4). It seems that the high pH's and its corresponding very high Ca content are provoking P fixation.

Previous studies have reported this same relationship between low phosphorus content in leaves and soils with high pH in maize crops [24].

3.4. Foliar Potassium (K) Content (%)

The nutritional status of *Creole Colima Tall* leaves in **Xul-ha** showed Potassium (K) sufficiency values of 1.4%, which is above the critical value of 1.17% (**Figure 4**). This is not the case of the *Tagnanan Hybrid* located in **Bacalar** with slight potassium deficiencies (1.0%), which could be related to other factors more than the K content in the soil since both locations have K values above 800 ppm (**Table 1**). It is suggested an antagonistic effect of the excessive Mg on K in the soil (1130 ppm).

Many studies attribute the nutritional deficiencies of K and other macronutrients to the intrinsic characteristics of the coconut ecotypes evaluated. This is because they differ in terms of nutritional absorption even when the elements are available [10].

Regarding the ecotypes of **Bacalar 2-INIFAP**, it was observed normal K levels in all ecotypes ranging from 1.2% for *Markham Valley Tall* to 1.7% for both *Creole Michoacan Tall* and *Malayan Yellow Dwarf* (**Figure 4**).

3.5. Foliar Calcium (Ca) Content (%)

Regardless of the locations, a high foliar calcium content was found in the six cultivars, with 0.99%, 0.95%, 0.80%, 0.72%, 0.84%, 0.64% for *Creole Colima Tall*, *Tagnanan Hybrid*, *Rotuma Tall*, *Markham Valley Tall*, *Creole Michoacan Tall* and *Malayan Yellow Dwarf* respectively (**Figure 4**), exceeding in more than 100% the critical limits reported by Sobral (1998) and Magat (1991) [18] [19].

These contents are evident given the very excessive high Ca in the soils, ranging from 6000 and 11,600 ppm as compared to the critical level of 1000 to 2000 ppm (**Table 1**). The excessive concentrations of macronutrients in soils will not necessarily increase the macronutrient levels in the leaves of coconut palms [24] [25].

3.6. Foliar Magnesium (Mg) Content (%)

Regarding the *Creole Colima Tall*, Mg deficiencies of 0.11% were shown as compared to the critical level of 0.24% (**Figure 4**). This is despite the high Mg content in the soil (**Xul-ha**) of 490 ppm (**Table 1**).

On the other hand, in **Bacalar 1** the *Tagnanan Hybrid* showed optimal Mg content (0.24%) since the soils have excessive concentrations of Magnesium of 1130 ppm (**Table 1**). Regarding the ecotypes of **Bacalar 2-INIFAP**, it was observed that all four ecotypes showed Mg levels up to 50% below the critical value; *Creole Michoacan Tall* and *Malayan Yellow Dwarf* being the cultivars with the lowest levels with 0.11% (**Figure 4**).

Even though the Mg in soils of **Bacalar 2-INIFAP** are in the optimal range (**Table 1**), it was not enough to properly nourish the plants. This could be related to an imbalance condition of soils where Mg is antagonized by the excess of Ca or K. Somasiri (1997) [26] reported that an increase in the application of K-based fertilizers would substantially affect the Mg nutritional status of coconut palm cultivars.

4. Conclusion

The content of N and P in all six cultivars were below the optimal level. It is assumed that N and P deficiencies are related to low N and P contents found in the soils. P deficiencies were found in all cultivars due to its low soil availability. At high pH values, the available form ($H_2PO_4^-$) can precipitate by reacting with calcium (Ca^{2+}) or magnesium (Mg^{2+}) to form slightly soluble phosphates such as tricalcium phosphate: $Ca_3(PO_4)_2$. Although all soils showed K contents in excess, deficiencies were still found in the *Tagnanan Hybrid* of **Bacalar 1** where Mg in the soil was extremely higher than those of the other locations; an antagonistic process is suggested. The Ca content in leaves of the six cultivars were above the optimal level as consequence of its very high concentration in the soils. Even though, all soils had Mg levels ranging from optimal to excess, five of the six cultivars showed Mg deficiencies excepting the *Tagnanan Hybrid* of **Bacalar 1** with the highest excess levels of Mg in the soil.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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