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Potassium (K^+) in Soil Profiles and Foliar Content as Related to K^+ at Two Depths over Time in Coconut Plantations of Guerrero, Mexico

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Abstract

Potassium (K) is a key nutrient in maintaining high levels of turgor and adequate water levels to regulate sugar during cell division. It is the most required during reproductive stage in coconut. Despite its importance, very little is known about its dynamic in soils. This study aimed to assess the content of K in soil deep *profiles* complemented with individual samples (IS) at 0 - 30 and 30 - 60 cm depth, taken during different years (year 1 and 4) in coconut plantations of Guerrero, Mexico. A Random Systematic Two-Dimensional Method (RSTDM) was used to select IS. A Completely Random Design was for soil profiles while a Multifactorial Random Block Design was for IS. Foliar analysis was taken to remark the relationship between soil and plant in year 4. In Costa Chica region the *Altos de Ventura* (*AV*) location was selected (*Profile* 1); in Costa Grande, two profiles were described, one in *Aguas Blancas* (*AB*) (*Profile* 2) and another in *Las Tunas* (*LT*) (*Profile* 3). No statistics differences were found between profiles. The average available K^+ in the profiles of *AV*, *AB*, and *LT* were: 0.34, 0.40, 0.51 $Cmol \cdot Kg^{-1}$, respectively; *AV* with the lowest and *LT* with the highest one. On the other hand, high statistic differences between factors (years, localities and depths) in the IS were found, but without interaction between factors. There was a decrease of K *over time* with, practically, a loss of 37% in all locations. Being 0.40 vs. 0.25 in *AV*, 0.37 vs. 0.23 in *AB* and 0.54 vs. 0.34 in *LT* until reaching the minimum of the Critical Level (0.25 - 0.86 $Cmol \cdot Kg^{-1}$) mainly in *AV* and *AB*. The leaves showed more K in *LT* with 0.99%

while the other locations had 0.83% (*AV*) and 0.82% (*AB*), all below the critical level of 1.6% reported for *Green Dwarf* coconuts.

Subject Areas

Agricultural Engineering

Keywords

Soil Fertility, Leaching, Green Dwarf Coconut, Critical Level

1. Introduction

Much has been said about the importance of potassium (K) in plants because its role in respiration, photosynthesis, chlorophyll appearance and water content in leaves (Devlin, 1975) [1]; it participates in different biochemical and physiological processes such as: enzyme activation, protein synthesis, photosynthesis, osmoregulation, stomatal activity, energy transfer, phloem transport, anion-cation balance and resistance to biotic and abiotic stress (Intagri, 2017) [2].

It is a key nutrient in the plant-water relationship, helping to maintain high levels of turgor and, consequently, adequate water levels in plants. Its importance is both quantitative and qualitative, as it regulates the availability of sugar during cell division.

After irrigation, fertilization is the practice that has the greatest impact on coconut productivity (Sobral, 1998) [3], since the amount of nutrients extracted by the coconut palm is high. This occurs because the plant develops rapidly and continuously, with flowering, fruiting, and fruit ripening all at the same time, requiring, therefore, constant application of fertilizers to achieve high production (Ohler, 1984) [4].

Keeping in mind that several research studies have shown that N and K supplementation are the most required by coconut palms (Ouvrier, 1984; Bonneau *et al.*, 1993) [5] [6], it is important to understand the dynamic of soil nutrients in order to improve the rational use of fertilizers in coconut cultivation is a compulsory task to soil scientists.

In that way, those cultivars growing in sandy soils, with low nutrient content, can achieve their maximum productive potential with optimal nutrient applications, thus making coconut a profitable crop for the families that depend on the activity.

Despite the important role that nutrition plays in coconut cultivation, little is known about the chemical characteristics of the Mexican soils where coconut is produced. Fertilization recommendations are based on a system of application and observation, without considering the initial soil supply, as this will determine the crop's response to fertilizer application.

This study aimed to assess the content and distribution of K in soil profiles through very deep horizons and complemented with individual samples at 0 - 30 and 30 - 60 cm depth taken during different years in coconut-producing areas of the state of Guerrero, Mexico. Foliar analysis was considered to remark the relationship between soil and plant.

2. Materials

Sampled Sites, Regions and Municipalities

The study was carried out in two separated years (year 1 and year 4) in the state of Guerrero, Mexico in Costa Chica and Costa Grande regions on Loamy Soils with a warm-sub-humid Aw0 climate (García, 1988) [7] and an average annual rainfall of 1200 mm. Three municipalities were selected, along with their corresponding *Green Dwarf* coconut plantations located between 16˚42'45" and 17˚05'51" North Latitude and −99˚13'08" and −100˚28'58" West Longitude.

According to Table 1 in the Costa Chica region, Municipality of San Marcos, just one site named *Altos de Ventura* (*AV*) was selected (*Profile* 1), whilst in Costa Grande, two profiles were described, one in the Municipality of Tecpán de Galeana, *Aguas Blancas* (*AB*) site (*Profile* 2) and one in the municipality of Benito Juárez, in *Las Tunas* (*LT*) (*Profile* 3). The description of *Profile* 3 in Las Tunas was carried out in an area affected by mud accumulation due to landslides caused by various hurricanes and floods.

In year 1 three soil profiles were described in the middle and representative part of each coconut plantations surface, where more detailed soil sampling was carried out at two depths, taking specific individual samples for each hectare: *AV* (9 has), *AB* (12 has) and *LT* (9 has). In year 4, only individual soil samples per hectare were taken to compare K changes over time.

Table 1. Location of soil profiles of coconut plantations studied in the state of Guerrero Mexico.

Profile (N˚)	Region	Municipality	Location	Geographic Coordinates
1	Costa Chica	San Marcos	*Altos de Ventura*	16˚42'44"N Lat. −99˚13'5"W Long.
2	Costa Grande	Tecpán de Galeana	*Aguas Blancas*	17˚11'5"N Lat. −100˚37'1"W Long.
3	Costa Grande	Benito Juárez	*Las Tunas* 1	17˚5'53"N Lat. −100˚28'55"W Long.

3. Methods

3.1. Sampling Soil Profiles

The horizons of each profile were identified by measuring their thickness (cm) according to color differences; the profiles were described until reaching one-meter depth. One-kilogram sample was taken from each horizon and sent to the Phytomonitor laboratory. The available K was extracted with Ammonium Acetate

(NH4 ac, pH 7.0) and the results were reported in Centi-Moles per Kilogram of soil ($Cmol \cdot Kg^{-1}$).

K contents were compared with those reported by the Mexican Official Standard (Nom-021-Semarnat-2000) [8] of 0.3 - 0.6 $Cmol \cdot Kg^{-1}$ and those of the Phytomonitor laboratory (2019) [9] with 0.25 - 0.86 $Cmol \cdot Kg^{-1}$. The last mentioned range [9] was used as a reference, for comparison purposes, since it covers the first one [8].

3.2. Statistical Analysis of Soil Profiles

The Coefficient of Variation (CV) is a statistical measure that indicates the relative variability of a data set relative to its mean. It is expressed as a percentage (%) and is calculated by dividing the standard deviation by the mean. It is useful for comparing the dispersion of different data sets. The results of available K obtained in the horizons of each profile were subjected to a CV analysis.

$$\mathrm{CV} = Sx/\overline{x}$$

X: Variable for which the variance is to be calculated.

Sx: Standard deviation of variable X.

$|\overline{x}|$: It is the mean of variable X in absolute value with $\overline{x} \neq 0$.

On the other hand, the K contents of the profile horizons were subjected to an Analysis of Variance (ANOVA) to observe statistical differences with a $p = 0.05$ in a Completely Randomized Design.

Any relationships between K^+ in the profiles and other soil attributes such as: Texture (% sand, silt, and clay), Cation Exchange Capacity (CEC in $Cmol \cdot Kg^{-1}$), Organic Matter (OM in %) and pH were quantified using correlation analysis (R^2).

3.3. Soil K at 0 - 30 cm and 30 - 60 cm Depth in Year 1 and Year 4

To better understand the changes of available K in the soil area, in this first year (year 1), beside the studies of soil profiles, individual soil samples (Ss), per each hectare, were taken at 0 - 30 cm and 30 - 60 cm depth: *AV* (9 Ss), *AB* (12 Ss) and *LT* (9 Ss).

After four years (year 4), the same areas were sampled taking 5, 5 and 9 Ss respectively at the same 0 - 30 and 30 - 60 cm depth.

For individual sampling, at two depths, a Random Systematic Two-Dimensional Method (RSTDM) was used. **Figure 1** shows a diagram as an example of 10 hectares where nine individual samples were taken. Each point in the hectare was randomly selected within the corresponding twelve grids on the diagram. Once the points were selected, their geographic position was recorded in order to continue with the specific sampling. In this case, a Random Block Design was used for the ANOVA considering the *Locations* as treatments and the *individual samples* as replications. Five individual samples per each location were considered as replications in a Multifactorial ANOVA with three Factors and their corresponding levels: Years 1 and 4 (2), Locations *AV*, *AB* and *LT* (3) and Depth 0 - 30 and 30 - 60 cm (2). Interactions between factors were evaluated.

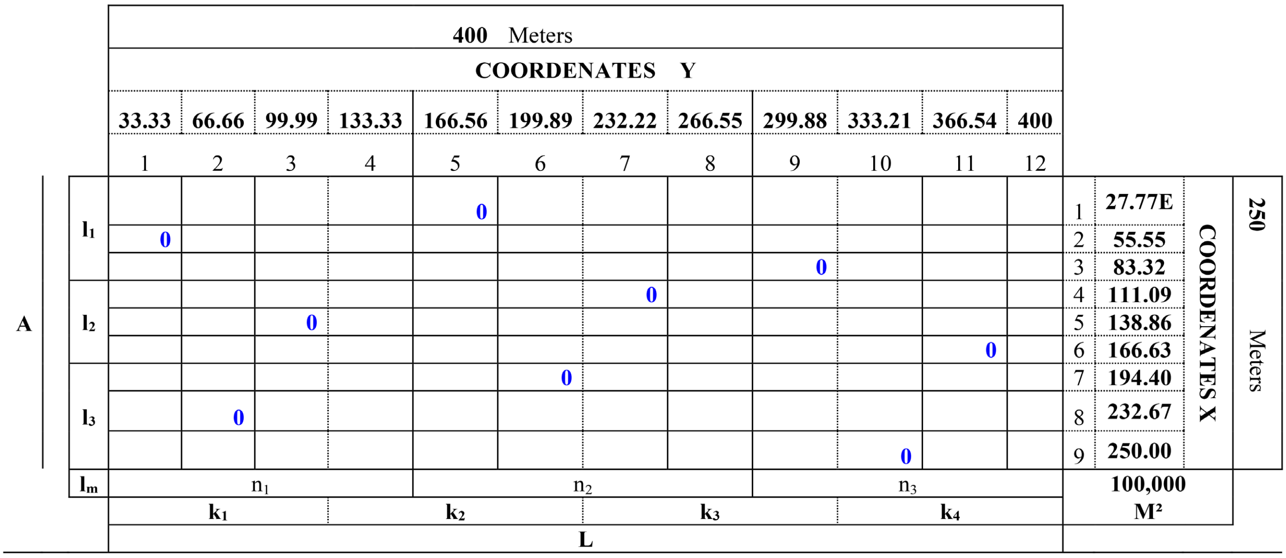

Figure 1. Diagram showing an example of soil sampling on 10 hectares using the RSTDM.

3.4. Foliage Sampling

Composite samples were taken on each location: 2 in *AV*, 2 in *AB*, and 3 in *LT*. Each composite sample was formed by three subsamples and, each subsample was taken from three randomly selected palms.

In each selected palm three leaflets of 20 cm length were extracted from the central part of leaf number 9. The K content was reported as percentage (%) and compared with the critical levels (1.6%) reported by Sobral (2018) [3] as reference value for *Green Dwarf* coconut cultivars.

4. Results

4.1. Available Potassium (K) in Different Soil Profiles

4.1.1. Altos de Ventura

Table 2 shows the concentration (Cmol·Kg^{-1}) and distribution of K along the soil profile in four different horizons found after excavation. The first above ground horizon had a thickness of 16 cm while the other three, underground ones were of 22 cm (16 - 38 cm), 48 cm (38 - 86 cm) and 24 (86 - 110 cm) with 0.56, 0.33, 0.26 and 0.23 Cmol·Kg^{-1} respectively.

The K average, through the entire profile was of 0.34 Cmol·Kg^{-1}, qualified as Sufficient and 36% above the minimum (0.25 Cmol·Kg^{-1}) of the sufficiency range.

It is noteworthy that K concentration, in the first three horizons are in the sufficiency range according to Phytomonitor [9]; the last and deepest horizon (86 - 110 cm) was the only one with available K below the Critical Level.

In Table 3, other soil attributes of *AV* such as Texture, CEC, OM and pH are being shown. The Loamy and Silty Loam are the predominant textures, with an average of 34%, 42% and 24% of sand, silt and clay respectively. In general, the CEC is in the High range and OM is Low in all deeper horizons, but high in the surface. There is a trend of the pH going higher, above eight, at deeper horizons no appropriate to most cultivated plants.

Table 2. Concentration of available K ($Cmol \cdot Kg^{-1}$) in different horizons and soil depths in Altos de Ventura, Municipality of San Marcos Guerrero, Mexico.

Horizon (N˚)	Depth (cm)	Available K^+ ($Cmol \cdot Kg^{-1}$)	Sufficient/deficient
1	0 - 16	0.56	Sufficient
2	16 - 38	0.33	Sufficient
3	38 - 86	0.26	Sufficient
4	86 - 110	0.23	Deficient
		Average 0.34	Sufficient

Critical Level: 0.25 - 0.86 $Cmol \cdot Kg^{-1}$.

Table 3. Soil attributes related to available K in different horizons of *profile* 1 in Altos de Ventura Municipality of San Marcos Guerrero, Mexico.

Horizon (N˚)	Depth (cm)	Texture	Sand (%)	Silt (%)	Clay (%)	CEC ($Cmol \cdot Kg^{-1}$)	O.M. (%)	pH H_2O (1:1)
1	0 - 16	Loamy	37	38	25	24.78	4.15	7.39
2	16 - 38	Loamy	51	28	21	23.29	1.01	8.66
3	38 - 86	Silty Loam	27	50	23	25.54	0.87	8.80
4	86 - 110	Silty Loam	21	52	27	27.31	0.60	8.48
		Average:	34	42	24	25.23 (High)	1.65 (Medium)	8.33 (High)

4.1.2. Aguas Blancas

Table 4 shows the results of K concentrations in each soil horizon at Aguas Blancas. It was found that all available K were above the sufficiency range, so no K deficiency in coconut plants are expected. The first above-ground horizon was found between 0 - 20 cm depth while the others three underground ones were found at 20 - 34 cm, 30 - 60 cm and 60 - 100 cm depth with 0.43, 0.38, 0.26 and 0.49 $Cmol \cdot Kg^{-1}$ respectively with an average of 0.40 $Cmol \cdot Kg^{-1}$ and 60% above the minimum of the sufficiency range.

Table 4. Concentration of available K ($Cmol \cdot Kg^{-1}$) in different horizons and soil depths in Aguas Blancas, Municipality of Tecpán de Galeana Guerrero, Mexico.

Horizon (N˚)	Depth (cm)	Available K^+ ($Cmol \cdot Kg^{-1}$)	Sufficient/deficient
1	0 - 20	0.43	Sufficient
2	20 - 34	0.38	Sufficient
3	34 - 60	0.26	Sufficient
4	60 - 100	0.49	Sufficient
		Average 0.4	Sufficient

The Sandy Loam (Table 5) is the most predominant texture in the horizons, increasing Sand and diminishing Silt as compared to the texture in *A V*. The CEC of 20 Cmol·Kg^{-1} is in the Medium Range (15 - 25 Cmol·Kg^{-1}) as well as the OM.

Table 5. Soil attributes related to available K in different horizons of *profile* 2 in Aguas Blancas Municipality of Tecpán de Galeana, Guerrero, Mexico.

Horizon (N˚)	Depth (cm)	Texture	Sand (%)	Silt (%)	Clay (%)	CEC (Cmol·Kg^{-1})	O.M. (%)	pH H_2O (1:1)
1	0 - 20	Sandy Clay Loam	57	10	33	17.08	2.55	6.1
2	20 - 34	Sandy Loam	65	26	9	17.09	1.68	6.2
3	34 - 60	Sandy Loam	73	20	7	14.52	1.74	6.42
4	60 - 100	Silty Clay	15	42	43	33.03	1.07	7.16
		Average:	53	25	23	20 (Medium)	2.00 (Medium)	6.00 (Slightly acid)

4.1.3. Las Tunas

Table 6 shows the K contents at different depths in *Profile* 3 of *Las Tunas*. All horizons showed values around 0.50 Cmol·Kilo^{-1}. The first above ground horizon of 0 - 30 cm thick showed a concentration of 0.54 Cmol·Kilo^{-1} similar to the others three underground horizons with values of 0.51 Cmol·Kilo^{-1}.

Table 6. Concentration of available K (Cmol·Kilo^{-1}) in different horizons and soil depths in *Las Tunas* 1 (*Profile* 3). Municipality of Benito Juarez Guerrero, Mexico.

Horizon (N˚)	Depth (cm)	Available K^+ (Cmol·Kg^{-1})	Sufficient/deficient
1	0 - 30	0.54	Sufficient
2	30 - 52	0.51	Sufficient
3	52 - 92	0.51	Sufficient
4	92 - 116	0.51	Sufficient
		Average 0.51	Sufficient

Critical Level: 0.25 - 0.86 Cmol·Kg^{-1}.

In the case of Las Tunas, Silty Loam (Table 7) was the most predominant texture with predominant amount of Silt in all horizons with the exception of the first surface horizon with more Sand than Silt. The average CEC of 16.27 Cmol·Kg^{-1} was the lowest than the other profiles, almost in the Low range of 8 - 15 Cmol·Kg^{-1} reported by the literature. The OM is not so high (1.83%), but it is in the Medium range (1.6% - 3.5%).

4.2. Available Soil Potassium (K) at 0 - 30 cm and 30 - 60 cm Depth in 2 Different Years

Table 8 shows the changes of available K in the three studied locations, where individual samples were taken, at both 0 - 30 cm and 30 - 60 cm depth. It was

Table 7. Soil attributes related to available K in different horizons of profile 3 in Las Tunas Municipality of Benito Juarez, Guerrero, Mexico.

Horizon (N˚)	Depth (cm)	Texture	Sand (%)	Silt (%)	Clay (%)	CEC ($Cmol \cdot Kg^{-1}$)	O.M. (%)	pH H_2O (1:1)
1	0 - 30	Sandy Loam	47	48	5	17.33	2.14	6.84
2	30 - 52	Silty Loam	27	70	3	12.44	1.01	7.07
3	52 - 92	Silty Loam	17	68	15	20.98	3.62	7.06
4	92 - 116	Silty Loam	27	64	9	14.33	0.54	7.92
		Average	29.5	62.5	8	16.27 (Medium)	1.83 (Medium)	7.2 (Neutral)

Table 8. Available K in different coconut plantations, years and depths in Guerrero, Mexico.

Location	Year (No.)	Number of Individual Samples	Depth (cm)		Average by years	Average both depths per location
			0 - 30	30 - 60		
AV	1	9	0.58	0.22	0.40	0.32
	4	5	0.34	0.17	0.25	
ABs	1	12	0.42	0.32	0.37	0.30
	4	5	0.32	0.15	0.23	
LT	1	9	0.58	0.51	0.54	0.44
	4	9	0.50	0.19	0.34	
Average by depths			0.45	0.26		

observed that K always decreased from 0 - 30 cm to 30 - 60 cm and the same trend happened with the years. Regardless of the years and locations, there was a 43% reduction of K when passing from 0 - 30 cm (0.45 $Cmol \cdot Kg^{-1}$) to 30 - 60 cm (0.26 $Cmol \cdot Kg^{-1}$) depth.

On the other hand, regardless of locations and depths, there was an important K reduction of 37% with the years; 0.43 $Cmol \cdot Kg^{-1}$ being the value of year 1 vs. 0.27 $Cmol \cdot Kg^{-1}$ of year 4. Observing the locations, regardless of depths and years, *LT* was the location with the highest K content with 0.44 $Cmol \cdot Kg^{-1}$ whilst as for *AV* and *AB* there was a reduction of 27.2 to 31.8%, with 0.32 and 0.30 $Cmol \cdot Kg^{-1}$ respectively. However, *AV* was the location with the lowest amount of available K in both depths; all locations showed to be in the sufficiency levels (Critical Level: 0.25 - 0.86 $Cmol \cdot Kg^{-1}$) at 0 - 30 cm in any year.

4.3. Statistical Analysis

4.3.1. Coefficient of Variation and Analysis of Variance (ANOVA) of Profiles

Table 9 shows the Means, Standard deviations, and CVs for each of the three soil profiles. It can be seen that the two plots: *AV* and *AB*, without extreme flooding, had the lowest average K values, with 0.34 and 0.39 Cmol/kg, respectively; while *LT*, with extreme flooding, showed higher average values, with 0.51 Cmol/kg.

On the other hand, the CVs ranged from the lowest 2.9% in *LT* to 43% in *AV*. In *AB* the CV was intermidiate with 25%. Considering the statement of Muñoz *et al.* (2006) [10] who mentioned that CVs less than 10% are low and 20 to 40% are intermediate, practically no profile showed any significant variability in the available K content at different depths.

Table 9. Means, Standard deviations (Sd) and Coefficients of Variation (CV) for K concentrations ($Cmol·Kg^{-1}$) distributed across different horizons of soil profiles in farms of Costa Grande and Costa Chica, Guerrero, Mexico.

Profile (N˚)	Average Available K^+ ($Cmol·Kg^{-1}$)	Standard deviation (Sd)	CV (%)
1 (*AV*)	0.34	0.149	43%
2 (*AB*)	0.39	0.098	25%
3 (*LT*1)	0.51	0.015	2.9%
4 (*LT*2)	0.51	0.210	40%

The ANOVA of soil profiles shown in **Table 10** suggests that no statistical differences were found between locations nor between horizons, regardless of the thickness of each horizon, since both probabilities (p) were above 5% (0.05).

Table 10. ANOVA of Soil Profiles in four-coconut plantation. Guerrero, Mexico.

Source of Varrietion	*Square sum*	*Degree of Freedom*	*Mean Square*	*F*	p (0.05)
Locations	0.06405	2	0.0320	3.592	0.094
Horizons	0.04269	3	0.0142	1.596	0.286
Error	0.05348	6	0.0089		
Total	0.16022	11			

Table 11. Correlation Coefficients (R^2) between available K of different horizons of Profiles 1, 2 and 3 and other soil attributes such as Texture (Sand, Silt, Clay), CEC, OM and pH in Guerrero, Mexico.

Profile (N˚)	Sand	Silt	Clay	CEC	OM	pH
1 (*AV*)	0.18	0.24	0.00	0.20	0.96	0.84
2 (*AB*)	0.71	0.20	0.78	0.60	0.037	0.20
3 (*LT*1)	0.86	0.94	0.14	0.03	0.023	0.29
Average	29.5	62.5	8	16.27 (Medium)	1.83 (Medium)	7.2 (Neutral)

When Correlation Coefficients (R^2) were calculated (**Table 11**) between available K (**Table 2**, **Table 4** and **Table 6**) and the different soil attributes (**Table 3**, **Table 5** and **Table 7**) (Texture, CEC, OM and pH), it was found that the relationship was not the same between profiles. The different soil attributes do not influence the available K in the same grade. In *AV*, OM and pH correlated better than CEC and Texture with very high R^2s of 0.96 and 00.84 respectively.

In the case of *AB*, the Texture correlated better than the other soil attributes with 0.78 and 0.71 for Clay and Sand respectively. The same thing happened with *LT* where Silt and Sand were the most influential on the concentration of K with very high R^2s of 0.94 and 0.86 respectively. The CEC is the only soil attribute that did not stand out; a slight influence was on *AB*, with an R^2 of 0.6.

4.3.2. Multifactorial Analysis of Variance (ANOVA) of Individual Samples Taken in Coconut Plantations

Table 12 suggests significant statistical differences among years, locations, and depths within the sampling area. This indicates that no location behaves chemically the same, and K, as well as other elements, must be treated in a very specific manner depending on the location. This was not the same trend noted in the *profile* analysis on which no differences were shown among locations nor between depths. However, should be noted that the number of profiles needs to be more; although the expensive cost needs to be considered. Anyway, the analysis of the soil *profiles* permitted to elucidate more about the relationship between available K and other soil attributes. On the other hand, there were not found any interactions between Factors so the effect of one factor does not depend on the level of the other factor because they work independently.

Even with the restriction of the low number of samples taken from a very large area planted with coconut, the study revealed that the plots are physically and chemically heterogeneous. Therefore, it is important to suggest that farmers conduct soil fertility studies on their own farms and plan their own fertilization treatments.

Table 12. Multifactorial ANOVA of three-coconut plantation, Guerrero, Mexico.

Source of Varrietion	*Square sum*	*Degree of Freedom*	*Mean Square*	*F*	*p* (0.05)
Years (A)	0.294	1	0.294	10.11	0.0026
Locations (B)	0.321	2	0.160	5.53	0.0069
Depths (C)	0.365	1	0.365	12.55	0.0009
INTERACTIONS:		3	0.0142	1.596	0.286
AB	0.046	2	0.023	10.80	0.456
AC	0.039	1	0.039	1.36	0.249
BC	0.001	2	0.000	0.03	0.971
*AB*C	0.100	2	0.050	1.73	0.187
Residues	1.396	48	0.029		
Total	2.56	59			

5. Discussion

Sandy soils typically have low Cation Exchange Capacity (CEC) and poor nutrientholding capacity. As a result, potassium ions (K^+) are more susceptible to leaching, especially in regions with high rainfall or over-irrigation. This process depletes soil potassium reserves, exacerbating potassium deficiency in coconut palms.

The soils of the area, where this work was carried out, have high leaching capacity such as: *Silty Loam*, *Sandy Loam* Texture with important contents of Sand classified as *Regosols* according to the WORLD RESOURCE BASE (WRB 2006) [11]. This means that, as mentioned above, the soils are very permeable ones, with high leaching capacity for potassium to be lost into deeper horizons. However, that is not the case of this study since the principal trend was to have higher amount of K in the less deep horizons.

The foregoing could be related to the fact that coast of Guerrero has suffered by different flooding, landslides, and sludge accumulation during the rainy and hurricane seasons as in the case of Hurricane Ingrid and Storm Emanuel in 2013 (Raga *et al.*, 2013) [12].

On the other hand, the highest available K in *LT* could be related to the fact that farmers of this location use fertilizers and organic materials for their coconut plantations while in *AV*, according to interviews, the use of fertilizers is more restricted.

When observing the changes of K in year 1 vs. year 4 (**Table 7**) it is obvious that there was a decrease of K ($Cmol·Kg^{-1}$) over time with, practically, a loss of 37% in all locations. Being 0.40 vs. 0.25 in *AV*, 0.37 vs. 0.23 in *AB* and 0.54 vs. 0.34 in *LT* until reaching the minimum of the Critical Level (0.25 - 0.86 $Cmol·Kg^{-1}$) mainly in *AV* and *AB*.

According to **Table 2**, **Table 4** and **Table 6**, the average available K^+ in the three profiles were: 0.34, 0.40, and 0.51 $Cmol·Kg^{-1}$ in *AV*, *AB*, and *LT* respectively. *AV* being the location with the lowest soil potassium (0.34) and *LT* with the highest one.

In order to see whether there is any relationship between the K in the soil and that found in the plant, it was necessary to make a comparison of both attributes, taking into account the K contents in the leaves (**Table 13**).

Table 13. K contents in leaves of four Coconut plantations in Guerrero Mexico.

Locations	Foliar K (%) Composite Sample			Average
	1	2	3	
Altos de Ventura	0.72	0.93		0.83
Aguas Blancas	0.70	0.95		0.82
Las Tunas	0.98	0.82	1.19	0.99

When matching both attributes (**Table 14**), it was found, at first glance, that when increasing the amount of available soil K, at the highest levels, as in the case of *LT,* the coconuts also reached the highest levels of K in the plant with 0.99%. However, it is important to mention that the sufficiency status depends on the coconut material. As for Giant materials, 1.1% in the palm is sufficient but not for the *Green Dwarf* which K levels needs to be of 1.6%.

Although the K in soils was good in year 1, the K levels diminished substantially in year 4, not enough to supply the demand of the *Green Dwarf* even in the best soil of *LT* with 0.99% and worst for *AV* and *AB* with 0.83% and 0.83% respectively.

Table 14. Matching Average Available K in the soil (Soil profiles and samples at both depths) and K in leaves of three Coconut plantations in Guerrero Mexico.

Location	Average Available K^+ in profiles (year 1) ($Cmol \cdot Kg^{-1}$)	Average Available K^+ both depths (year 1) ($Cmol \cdot Kg^{-1}$)	Average Available K^+ Both depths (year 4) ($Cmol \cdot Kg^{-1}$)	Average Foliar K (%)
AV	0.34	0.40	0.25	0.83
AB	0.39	0.37	0.23	0.82
LT	0.51	0.54	0.34	0.99

According to the results, it is clear that the soils dedicated to coconut palms, in the studied areas, can offer sufficient amounts of exchangeable K to the crop. However when time is passing by, the soil can be depleted if fertilization with organic or inorganic materials are not added. However, there are reports indicating that additional fertilization does not substantially increase nut yields per tree (Mahindapala, 1981) [13].

Likewise, other authors found no response when applying N, P, and K in the state of Tabasco, Mexico (Domínguez, cited by Ordaz (2001) [14]. However, Ordaz and Pérez (1998) [15] recommended applying 1.9 kg of KCl and 1.2 kg of $(NH_4)_2SO_4$ per palm but the response will depend on the variety, soil, and agronomic management.

It has been reported (Pérez Zamora, 2003) [16] that applying only K (0 N - 0.8 K) the number of coconuts per palm, copra per palm and copra per nut increased 18.9% related to the control. However, applying it in combination with nitrogen (N) (0.8 N - 0.8 K and 0.4 N - 1.6 K) significantly increased the number of coconuts per palm and the amount of copra per palm by 34%, eight and twelve months after applying fertilizers.

6. Conclusions

Even though coconut is of relevant importance in the tropics, there are topics deserving detailed studies, such as the *soil-plant* relationship. The study of potassium is of utmost importance since coconut palms require it more than other elements during the reproductive stage.

In this work, the soil of coconut plantation was monitored, analyzing K content in soil profiles at 1 meter depth, complemented with individual samples at two depths (0 - 30 cm, 30 - 60 cm), comparing K changes over time and with foliage contents.

The main conclusions were as follows:

1) The soil horizons in the soil profiles of all locations were in the sufficiency range of 0.25 - 0.86 Cmol·Kg^{-1}. *LT* showed the highest average available K with 0.51 Cmol·Kg^{-1}, while *AV* and *AB* with 0.34 and 0.40, respectively.

2) There was a decrease of K over time with practically a loss of 37% in all locations. Being 0.40 vs. 0.25 in *AV*, 0.37 vs. 0.23 in *AB* and 0.54 vs. 0.34 in *LT* until reaching the minimum of the Critical Level (0.25 - 0.86 Cmol·Kg^{-1}) mainly in *AV* and *AB*.

3) Even though *LT* had the highest soil K, it did not cover the demand of the Green Dwarf.

4) When time is passing by, the soil tends to be depleted if fertilization with organic or inorganic materials is not added; so a strong Fertilization Program needs to be launched.

5) The study revealed that the plots are physically and chemically heterogeneous in both *in-situ* and *ex-situ*. Therefore, it is important to suggest that farmers conduct soil fertility studies on their own farms and plan their own fertilization treatments.

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Conflicts of Interest

The authors declare no conflicts of interest.

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