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Heterogeneity and Spatial Distribution of Inorganic Nitrogen as Nitrate ($N\text{-}NO_3$) in Two Soils Dedicated to Green Dwarf Coconut in Guerrero, Mexico

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Abstract

The productivity of coconut in Guerrero, Mexico has decreased substantially. The experts recommended a diagnosis of the soil fertility before launching a sound reforestation program. The introduction of Green Dwarf Coconut (GDC) due to its high productivity was suggested; however, nitrogen (N) was of higher interest since GDC is a highly demanding material. In this work, the contents, in parts per million (ppm), of nitrogen (N) as nitrate ($N\text{-}NO_3$) as well as its chemical variability (Coefficient of Variation) and spatial distribution (Kriging method) was determined at 0 - 30 and 30 - 60 cm deep in the soil. Two GDC commercial plantations were selected and the study was complemented with foliar N (%) analysis. Two farms: *Las Tunas* (LT) of 9 hectares and *Aguas Blancas* (AB) of 5 hectares were sampled taking one point per hectare at both depths, one meter from the trunk. In LT, the overall average of $N\text{-}NO_3$, at 0 - 30 cm, was rated as MEDIUM and at 30 - 60 cm as LOW. On the other hand, in AB the general average of $N\text{-}NO_3$ was graded as LOW at both depths. The two farms showed important chemical heterogeneity as indicated by the HIGH CV's (%). Regardless of the specific values of N, in LT the spatial distribution of N seems to be the same between both depths with an approximate area of 20% classified as LOW (14 - 18 ppm) and 80% as MEDIUM 20 - 28 (ppm). On the other hand, in AB the spatial distribution was contrasting between depths. At 0 - 30 cm deep, an approximate area of

15% was rated as LOW and 75% as MEDIUM whilst at 30 - 60 cm deep, 70% was LOW, 28% MEDIUM and just 2% HIGH. Although both farms showed LOW foliar N contents, as compared to the critical range of 1.8% - 2.0%, AB was the one reporting the lower N value of 1.16% vs. LT with 1.44%, both in deficiency levels.

Subject Areas

Agricultural Engineering

Keywords

Kriging, Foliar N, Deficiency, Heterogeneity, Critical Level

1. Introduction

The coconut palm (*Cocos nucifera* L.) is cultivated in 87 countries [1]. Although it was introduced in Mexico more than a century ago, it began to be incorporated as a commercial crop in the 1940's [2]. The main product was the copra production for the soap industry. For several years, copra moved the economy of both the Gulf and Pacific coastal areas [3].

Coconut palm cultivation has been increasing in recent years, not only in Latin America but also, in various parts of the world. However, Mexico is facing a constant reduction due to aging of plants and continuous drop in prices.

In addition, the coconut is generally cultivated in sandy coastal areas with low fertility, causing low productivity. However, despite the economic importance of this species, the studies on mineral nutrition are of little importance; and the available information mainly refers to tall varieties [4] (Santos *et al.*, 2004).

Soil analysis, is of vital importance, since mineral nutrient deficiencies reduce the number of female flowers which eventually causes "*immature fruit abortion*" [5] [6]. The nutritional balance is essential to have a high sustainable productivity of the coconut palm [7].

Therefore, considering that in recent years the introduction of new eco-types of coconut, such as the Green Dwarf Coconut of Brasil (GDC), has been promoted in Guerrero Mexico, it was of great importance to present this study related to soil fertility.

The first studies on soil fertility were carried out in 2015 by Ramírez *et al.* (2015) [8] who observed that the contents of Nitrogen as Nitrates (N-NO_3) was, among other essential nutrients, the main deficient element in the soil. At that time, the authors recommended putting specific attention to nitrogen when launching a sound fertilization program.

Taking into account the foregoing considerations and that GDC is a highly Nitrogen (N) demanding crop, the objective of this work was to evaluate, again, the nutritional content of inorganic nitrogen as nitrate (N-NO_3), its grade of heterogeneity and spatial distribution in soils of two commercial plantations with

GDC.

2. Materials and Methods

2.1. Locations

The study was carried out in the dry season of 2019 in the state of Guerrero Mexico located between 16˚42'45" to 17˚05'51" North Latitude and 99˚13'08" to 100˚28'58" West longitude. The soils were Regosols according to the World Reference Base for Soil Resources (WRBSR) with Sandy Loam, Silty Loam and Clay Loam textures.

Two Green Dwarf Coconut (GDC) plantations were selected in the Costa Grande region with a warm sub-humid Awo climate [9] and a mean annual rainfall of 1200 mm. The first 9 hectares plantation was *Las Tunas* Farm (LT) in the municipality of Benito Juárez located in the coordinates: 17.096790 North Latitude and 100.48046 West Longitude and the second 4 hectares one was *Aguas Blancas* Farm (AB) in the municipality of Técpan de Galeana located at the coordinates: 17.18375 North Latitude and 100.61782 West Longitude.

2.2. Soil Sampling

For both plantations, an individual soil sample per hectare was taken. The LT and AB farms had 9 and 5 homogeneous hectares, respectively, from which samples were taken at a distance of one meter from the trunk at 0 - 30 and 30 - 60 cm deep. It is reported that 7 to 20 sub-samples per 5 to 10 hectares are appropriate for homogeneous surfaces [10].

2.3. Foliar Sampling

The foliar samplings were carried out from palms in full competition considering leaf number 9 as suggested by Sobral (1998) [11]. A composite foliar sample was taken for every 2 - 3 hectares. All composite samples were formed by mixing three sub-samples, and each sub-sample was formed with 15 pieces of 20 cm from the same number of leaflets taken from three palm trees (5 leaflets per tree). The leaflets were taken from the middle third of leave number 9; cuts of 20 cm were made in each leaflet in the middle third of each one.

2.4. Soil and Foliar Chemical Analysis

The soil $N-NO_3$ was reported in Parts per Million (ppm) [12] using Brucina method, The $N-NO_3$ is the form most used by plants [13]. The Kjeldall method was used to determine the Total Nitrogen (TN) in leaves (%).

The soil and plant N were compared with reference values. For soils, the optimal levels in ppm (**Table 1**) was based on Mexican Standards [14]. For leaves, the critical values (**Table 2**) varies from 1.8% to 2.0% [15] [16]. The direct interpretation is the main advantage of this method when matching recorded values with the critical levels.

The Coefficient of Variation (CV) in percentage (%) of soil $N-NO_3$ (ppm) was

Table 1. Reference levels of Inorganic Nitrogen suggested by the SEMARNAT (2002). [14].

Soil Test Rating	N-NO_3 (ppm)
Very Low (VL)	0 - 10
Low (L)	10 - 20
Medium (M)	20 - 40
High (H)	40 - 60
Very High (VH)	>60

Table 2. Optimal contents of Total Nitrogen (%) in leaf number 9 of different coconut eco-types reported by literature.

Coconut Eco-type	Total N (%)	References
Tall	2.2	Magat (1991) [15]
Hybrid	2.2	Magat (1991) [15]
Green Dwarf	1.8 - 2.0	Sobral and Santos (1987) [16]

calculated to understand the grade of soil chemical heterogeneity. The higher the CV value, the greater the heterogeneity of the variable. Normally, in agricultural field trials, CV's are considered Low (L) when they are less than 10%; Medium (M) from 10% to 20%, High (H) from 20% to 30% and Very High (VH) above 30% according to Pimentel (1985) [17].

2.5. Spatial Distribution of N-NO_3

Kriging' principles are based on that unknown; non-sampled-regions can be correlated using the sampled ones, due to the existing variance rate between samples in a physical continuity. Contrasting to the traditional statistical methods, which consider all samples points as independents, Kriging assumes that samples taken close to another may have similar values [18]. The spatial distribution and the interpolation was performed by using the Gammadesign (GS+) software (2018) [19]. The geo-statistical process started in the field, taking the geographic coordinates (Latitude and Longitude) of each specific sampled point. Kriging was used to interpolate values for those un-sampled points across the spatial field. The data was adjusted under Random Deterministic Models [20] and the values were predicted along the specific areas. This interpolation method is attractive thanks to obtaining the Standard Error of the predicted values [21].

3. Results and Discussion

3.1. Soil Nitrogen (N-NO_3) Content in *Las Tunas* and Its Variability

Table 3 shows the contents and overall average of N-NO_3 (ppm) and the CV's of LT at two depths. The general average of 29.6 ppm, at 0 - 30 cm, ranked as MEDIUM whilst at 30 - 60 cm the rating was LOW with 19.7 ppm, very close to

Table 3. N-NO_3 content (ppm) and heterogeneity (CV) at 0 - 30 and 30 - 60 cm deep in soils of *Las Tunas* farm in Costa Grande. Municipality of Benito Juarez. Guerrero, Mexico.

Sample (No.)	0 - 30 cm	30 - 60 cm
1	28.8 (M)	52.8 (A)
2	31.2 (M)	20.0 (M)
3	24.8 (M)	10.4 (B)
4	12.8 (L)	9.6 (MB)
5	16.8 (L)	23.2 (M)
6	16.8 (L)	3.2 (MB)
7	98.8 (VH)	36.8 (M)
8	13.6 (L)	4.0 (VL)
9	23.2 (M)	17.6 (L)
Average	29.6 (*M*)	19.7 (*L*)
CV (*%*)	90.2 (*VH*)	82.3 (*VH*)

MEDIUM (20 - 40 ppm).

The 44.44% of the 9 samples, at 0-30 cm, were in the MEDIUM range (4) and the same percentage was for the LOW range (4); while only one sample was qualified as VERY HIGH, representing 11.12%.

At 30 - 60 cm deep, 33.33% of the samples were classified as MEDIUM (3), the same percentage as VERY LOW (3), 22.22% of (2) as LOW and 11.12% (1) HIGH.

On the other hand, a great heterogeneity was noted in the 9 hectares at both depths, since the CV's were in the VERY HIGH range from 90.2% (0 - 30 cm) to 82.3% (30 - 60 cm).

Similar works [22], but in a longer period (12 years), suggests that the spatial variability is more important than the temporal variability to explain the content of available soil nitrogen (ammonium- and nitrate-nitrogen) using multivariate analysis. The coefficient of variation in a grassland ecosystem ranged very low [22] as compared to the VERY HIGH CV's of his specific work. Temporal factors related to anthropogenic activities (heterogeneity fertilization, burning of post-harvest wastes inside the coconut plantation, weeds control, fertilization etc.) should have influenced the higher CV's.

3.2. Soil Nitrogen (N-NO_3) Content in *Aguas Blancas* and Its Variability

Table 4 shows the N-NO_3 contents and CV's of AB at both depths. The overall average was greater at 0 - 30 cm deep (17.4 ppm) than that at 30 - 60 cm (10.8 ppm). However, both were classified as LOW. At 0 - 30 cm, 40.0% (2) of the 5 samples were MEDIUM and the same percentage was LOW; while at 30 - 60 cm 60% (3) was in VERY LOW and 20% (1) in LOW; the remaining 20% (1) was MEDIUM.

The CV's of AB were lower than those of LT with 46.7% and 52.1% for 0 - 30 and 30 - 60 cm deep respectively; however both classified as VERY HIGH heterogeneity [17].

In both farms, the general trend is a reduction of soil nitrates in the under layer (30 - 60 cm) as compared to the above ground (0 - 30 cm). This is the kind of trend reported by Yang *et al.* [23] in the case of a blank control, with no nitrogen applications, where in the early stage of a cucumber field, nitrate-nitrogen content in surface soil was significantly higher than that in soil layers deeper than 40 cm. In our specific case, it is probable that the roots of coconut palms are extracting more nitrogen at deeper layers than in the aboveground.

3.3. Foliar Total Nitrogen (%) in Green Dwarf Coconut

Any farm had sufficiency levels of N since all samples were below the critical range of 1.8% - 2.0% (**Table 5**). However, AB farm showed to be more deficient (1.16%) than LT (1.44%). All of the above indicates the need to pay close attention to the issue of nitrogen fertilization, whether in organic applications and/or chemical ones.

The fertilization should be carried out at least once a year to replenish the nutrients removed by the coconut harvest but the recommendations should be based on foliar analysis [24]. In the same sense, to keep the coconut plant in a good nutritional state, the extracted nutrients must be replaced, and the only way to know the amount replaced is with soil and foliar analysis [25]. The effect of fertilization of fertilization is noticeable after 1.5 years in dwarf cultivars and after 2 years in tall ones.

Table 4. N-NO_3 content (ppm) and heterogeneity at 0 - 30 and 30 - 60 cm deep in soils of *Aguas Blancas* farm in Costa Grande. Municipality of Tecpan de Galeana. Guerrero, Mexico.

Sample (No.)	0 - 30 cm	30 - 60 cm
1	20.0 (M)	12.8 (L)
2	29.6 (M)	8.0 (VL)
3	8.0 (VL)	6.4 (VL)
4	16.8 (L)	7.2 (VL)
5	12.8 (L)	20.0 (M)
Average	17.4 (*L*)	10.8 (*L*)
CV (*%*)	46.7 (*VH*)	52.1 (*VH*)

Table 5. Foliar N (%) content in two Green Dwarft Coconut farms of Guerrero Mexico.

Farm	Sample 1	Sample 2	Sample 3	Sample 4	Average
Las Tunas	1.46 (L)	1.18 (L)	1.51 (L)	1.64 (L)	1.44 (L)
Aguas Blancas	1.44 (L)	0.88(L)	NS	NS	1.16 (L)

3.4. Spatial Distribution of N-NO_3 in *Las Tunas* and *Aguas Blancas*

The approximate spatial distribution of soil N-NO_3 in surface-percentage (%), at two depths and both farms, is shown in Table 6. The percentage was taken from Figures 1-4 where different colors are representing the distribution of contrasting

Table 6. Approximate spatial distribution in percentage (%) of N-NO_3 contents (ppm).

Farm	Grade	0 - 30 cm	30 - 60 cm
	Low	20.00%	20.00%
Las Tunas	*Medium*	80.00%	80.00%
	High	00.00	00.00
	Low	15.00%	75.00%
Aguas Blancas	*Medium*	85.00%	24.00%
	High	00.00	1.00

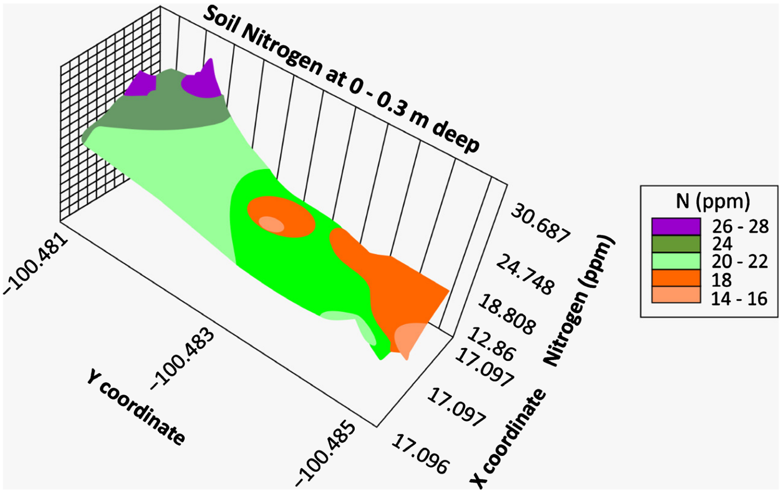

Figure 1. Spatial distribution of N-NO_3, at 0 - 30 cm deep in LT.

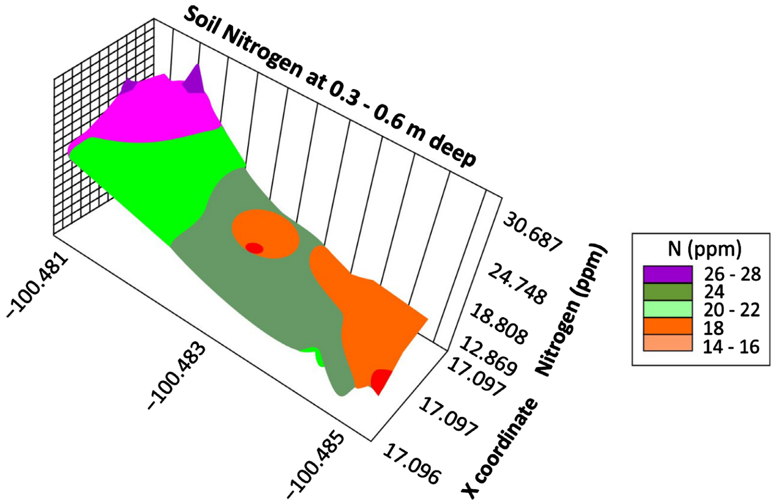

Figure 2. Spatial distribution of N-NO_3, at 30 - 60 cm in LT.

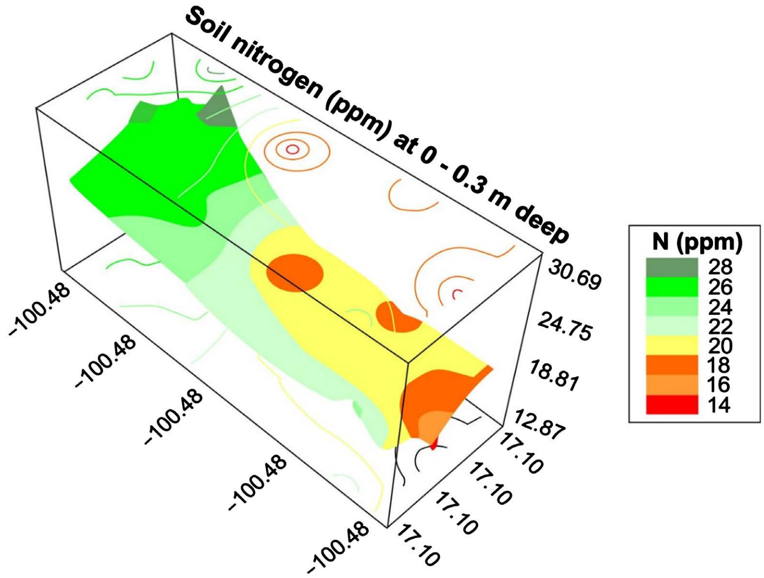

Figure 3. Spatial distribution of N-NO_3, at 0 - 30 cm deep in AB.

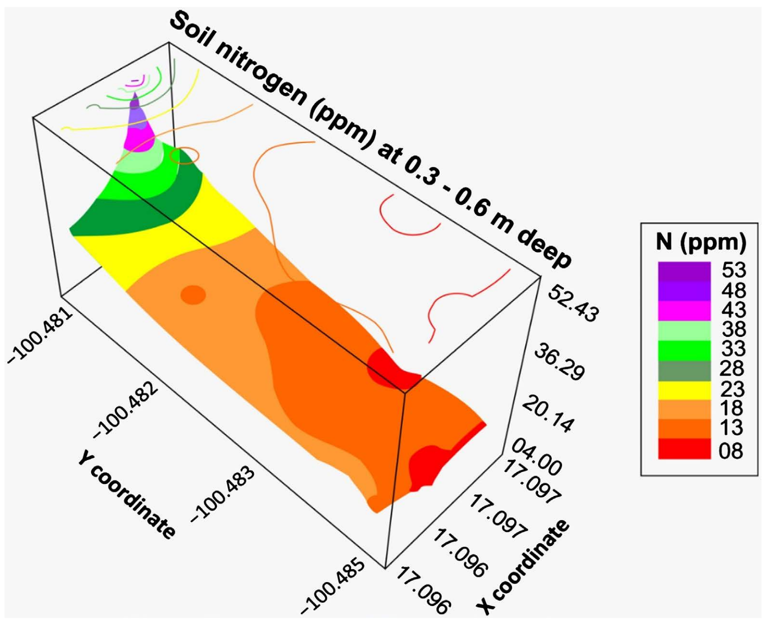

Figure 4. Spatial distribution of N-NO_3, at 0 - 30 cm deep in AB.

N levels (ppm) indicating sufficient or deficient N contents. Most of the surface (80%) in LT, at both depths, showed to be in optimal levels, ranking as MEDIUM (20 - 28 ppm) colored in GREEN and PURPLE and the remaining 20% as LOW (14 - 18 ppm) in orange COLORS as shown in **Figure 1** and **Figure 2**. There is a generally similar N spatial distribution between the above and the underground.

On the other hand, in AB the spatial distribution between depths is quite contrasting (**Figure 3** and **Figure 4**). At 0 - 30 cm, approximately 15% of the total 5 hectares, ranked as LOW (14 - 18 ppm), shown in RED and ORANGE colors; and 85% as MEDIUM (20 - 28 ppm) colored in YELLOW, BLUE and GREEN

(**Figure 3**). At 30 - 60 cm deep (**Figure 4**) 75% of the surface was LOW (8 - 18 ppm) in RED and ORANGE, 24% MEDIUM (23 - 36 ppm) in YELLOW and GREEN; and just 1% HIGH (43 - 53 ppm) in PURPLES.

4. Conclusion

In LT, the overall average of $N\text{-}NO_3$ at 0 - 30 cm was rated as MEDIUM and at 30 - 60 cm as LOW. On the other hand, in AB the general average of $N\text{-}NO_3$ was graded as LOW at both depths. The two farms showed important chemical heterogeneity as indicated by the HIGH CV's (%). Regardless of the specific values of N, the spatial distribution of N in LT seems the same between both depths with an approximate area of 80% classified as MEDIUM content and 20% as LOW. On the other hand, the spatial distribution in AB was contrasting between depths with an approximate area of 85% graded as MEDIUM and 15% as LOW at 0 - 30 cm. At 30 - 60 cm, 75% was LOW, 24% MEDIUM and just 1% HIGH. Although both farms showed LOW foliar N contents, as compared to the critical range of 1.8-2.0%, AB reported a lower N value of 1.16% and LT with 1.44%, both in deficiency levels.

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Conflicts of Interest

The authors declare no conflicts of interest.

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