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Soil Nitrogen (N-NO_3) as Related to Corn Nutrition When Applying Sulfuric Acid and Sub-Soiling to a Calcaric *rhodic Luvisol* of Yucatan Mexico

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Abstract

Nitrogen (N) is one of the essential elements that most limit corn production in the state of Yucatan. The high pH leads to high contents of hydroxyls (OH-) which, when reacting with available inorganic ionic forms such as NH_4^+, favor their volatilization as ammonia gas (NH_3). The red arable *rhodic Luvisols* of Yucatan Mexico, in addition to facing alkalinity problems, have been exposed to more than 30 years of intensive corn cultivation with consequent soil compaction and negative collateral effects. In this work, the effect of the application of acid and sub-soiling on the concentration of N-NO_3 in the soil and on the nutrition of maize *Chichen Itza* (*Nukuch Nah*) variety in a *rhodic Luvisol* was evaluated through the following treatments: T1 = Without Acid + Sub-soiling, T2 = Without Acid + No Sub-soiling, T3 = With Acid + Sub-soiling, T4 = With Acid + No Sub-soiling. The N-NO_3 in the soil were higher than the Critical Limit of 20 ppm when applying acid whilst where no acid was applied, the N-NO_3 were below the Critical Limit. On the other hand, regardless of the acid, when subsoiling, the amount of N-NO_3 in the soil decreased. The N (%) in leaves of all treatments were below the Critical Limit of 2.7%. It is noteworthy that the N content in leaves was higher (2.6%) With Acid + No sub-soiling while the lowest (2.45%) was Without Acid + Sub-soiling. The ANOVA of the treatments did not show statistical differences. However, a very good correlation was found between the soil N-NO_3 (ppm) vs. the N contents (%) in the plant ($r^2 = 0.98$).

Subject Areas

Agricultural Engineering

Keywords

Deficiencies, Alkalinity, Compaction, Nutrition

1. Introduction

Nitrogen (N) is one of the essential elements that most limits corn production in the state of Yucatan Mexico. Soils of calcareous origin have high pH's where the contents of hydroxyls (OH-'s) stand out and consequently react with N ions assimilable by plants such as NH_4^+, favoring its volatilization as ammonia gas (NH_3). This chemical process has been reported by Mills *et al.* since 1974 [1], mentioning that volatilization increases as pH increases, as a result of the increase of OH activity.

Studies carried out by Ramírez *et al.*, (2018) [2] reported average contents of 16 ppm of N-NO_3 in two calcaric *rhodic Luvisols*, below the critical limit of 20 ppm reported by the Official Mexican Standard (SEMARNAT, 2002) [3].

It has been commented that a third of the world's soils have the same genesis as those of Yucatan and consequently they face the same problems due to their alkalinity. This is a problem that can be solved with the application of acids as reported by Martínez-Garza (2003).

The effect of acid application on some chemical characteristics of a calcareous soil were reported by Ferreyra *et al.* (1998) [4] proving that Sulfuric and phosphoric acids were the most suitable for soil acidification. Drip irrigation with water acidified with sulfuric acid to a pH of 4.5 - 5.5 maintained an acidic pH for three seasons, in the substrate of the planting hole. The acidification of irrigation water prevented the loss of nitrogen as ammonia gas (NH_3) in fertigation with urea (Miyamoto *et al.* 1975) [5].

On the other hand, the calcaric red arable *Luvisols* of Yucatan, Mexico with better productive potential than the stony *Leptosols*, have been exposed to more than 30 years of intensive corn cultivation.

Even though the harmful effects of a compacted soil are known, it is very rare, for the local producers, to prevent the formation of compacted zones using sub-soiling practices. This can lead to a better aeration, greater microbial activity and nutritional availability (Chavez-Romero *et al.*, 2016, Huaying Shan, 2022) [6] [7].

The disadvantage of an intensive and continuous conventional tillage have been reported by different authors (Bayer *et al.*, 2000) [8] who mention that soil compaction can be amplified, driving to a reduction of water and nutrient availability and a long-term soil physicochemical and biodiversity degradation. By contrast, subsoiling can stimulate the formation of aggregates and consequently improve soil water availability (Bottinelli *et al.*, 2017) [9].

Soil compaction has been well founded in the corn belt of Frailesca, Chiapas, Mexico where 83.3% of the studied area presented superficial compaction and 94.6% compaction in the subsoil (plow floor). During the drought periods, the yields are reduced by 58%, which is correlated with the decrease of the porosity as a result of the compaction (López Baez *et al.*, 2018) [10].

Due to the foregoing, this work aimed to evaluate the effect of both the application of sulfuric acid and the sub-soiling on the concentration of Nitrogen as Nitrate (N-NO_3) in the soil and on the nutrition of a corn variety named CHICHEN ITZA (*Nukuch Nah*) in a *rhodic Luvisol* of Yucatan Mexico.

2. Materials

The work was carried out in the Autumn-Winter 2022/2023 cycle under drip irrigation conditions at the INIFAP-UXMAL Experimental Station on a red *rhodic Luvisol* in the state of Yucatan Mexico.

The yellow grain *Chichen Itza* variety with Protein Quality, established with 56 thousand plants ha^{-1} was used as a phytometer.

A vertical chisel was used to plow the soil and a basic fertilization with Diammonium Phosphate (18 N-46 P_2O_5-00 K_2O), 10 cm from the stem was applied. To acidify the soil, sulfuric acid (H_2SO_4) at 98% was injected.

3. Methods

Four treatments were tested considering the combination of (No Acid-Acid) and (Subsoiling-No Subsoiling) as follow: T1 = Without Acid + Sub-soiling, T2 = Without Acid + No Sub-soiling, T3 = With Acid + Sub-soiling, T4 = With Acid + No Sub-soiling.

The sub-soiling was done with chisel at a depth of 40 cm and plants were watered every day, but the sulfuric acid was injected into the drip irrigation system twice a week.

Six plants per each treatment, with complete competition, were selected to measure the influence of treatments on the content of N-NO_3 in the soil, measured in parts per million (ppm) and on the foliar Nitrogen (N) concentration, determined in percentage (%).

The leaves opposite to the ears, for all six plants, were sampled at the beginning of the reproductive stage. Subsequently, in the rhizosphere, of the same six plants, a composite soil sample was taken at harvesting time to be sent to the Phytomonitor Laboratory of Culiacán Sinaloa (Phytomonitor, 2022). [11]

The soil N-NO_3 contents were compared with the reference levels of 20 ppm of the Mexican Official Standard (SEMARNAT, 2002); [3] And the critical level of 2.7% was considered as a reference for foliage contents as reported by Jones Jr. *et al.* (1973) [12]. The treatments were distributed in a Completely Randomized Block design with two replications subjected to an Analysis of Variance (ANOVA) at 5%. The Coefficients of Determination ($\mathbf{r}^2$) to measure the relationship between N in the soil and the foliage was calculated.

4. Results and Discussion

4.1. The Nitric Nitrogen (N-NO_3) in the Soil

The N-NO_3 contents (**Figure 1**) were higher when applying acid, exceeding the

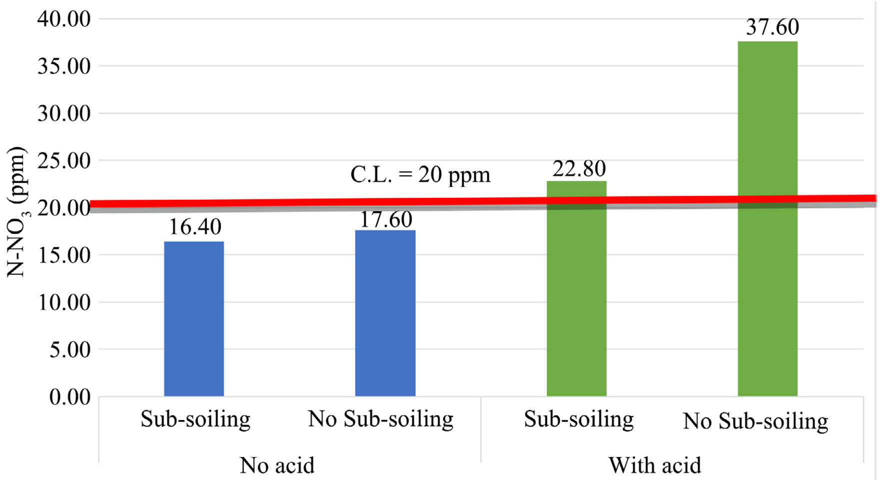

Figure 1. N-NO_3 content (ppm) in a *rhodic Luvisol* with sulfuric acid and sub-soiling.

Critical Limit (**C.L.**) of 20 ppm. When applying acid the ranges fluctuated from 22.8 With Sub-soiling (T4) to 37.6 ppm With no Sub-soiling (T3). When acid was not applied the N-NO_3 contents were below the critical range fluctuating from 16.40 With Sub-soiling (T2) and 17.60 ppm With no Sub-soiling (T1).

Regardless of Sub-soiling, the overall average of N-NO_3 With Acid (30.2 ppm) was 77% higher (17.0 ppm) than that of Without Acid. This indicates the advantage of sulfuric acid in the increment of available nitrogen in the soil.

On the other hand, regardless of the acid, the use of Sub-soiling decreases the N-NO_3 in the soil. The general average of N-NO_3 was 19.6 ppm with Sub-soliling vs. 27.6 ppm with no Sub-soiling; a reduction of 29% when Sub-soiling.

The influence of Sub-soiling on the decrease of N-NO_3 may be related to leaching losses when the soil increases its hydraulic conductivity when it is plowed.

Works related to subsoiling tillage have been conducted by different researchers as in the case of North China (Shaobo Wang, *et al.*, 2019) [13] where four tillage depths were studied: conventional tillage 25 cm (CT25); subsoiling tillage 30 cm (ST30); subsoiling tillage 35 cm (ST35) and subsoiling tillage 40 cm (ST40). Soil bulk density decreased by 4.59%, 7.13% and 8.27% and soil compactness by 17.62%, 23.63% and 36.42% when subsoiling was applied at 30, 35 and 40 cm deep respectively as compared to the conventional tillage.

In addition, subsoiling increased macroaggregates, improved the stability of the aggregates, increased soil water storage capacity and increased maize yield by more than 7.5%.

4.2. Nitrogen in Leaves (%) of Chichen Itza Corn

Figure 2 shows that N contents in corn leaves are below the Critical Limit of 2.7%. However, it is noteworthy that the N content was highest (2.6%) with T4 (With Acid + No sub-soiling) while the lowest (2.45%) was with T1 (Without Acid + Sub-soiling) similar (2.45%) to T2 (No Acid + No Sub-soiling).

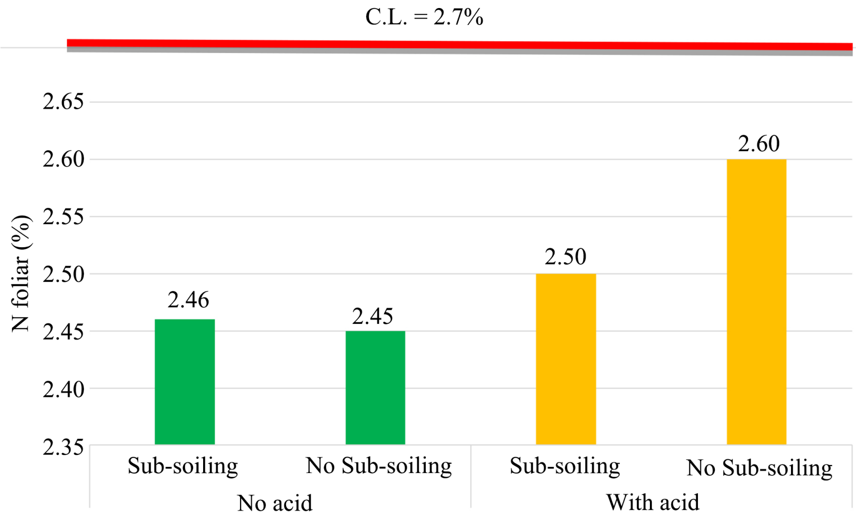

Figure 2. N content (%) in *Chichen Itza* (*Nukuch Nah*) corn leaves in a *rhodic Luvisol* with sulfuric acid and sub-soiling.

Although acid has a positive effect on nitrogen absorption, the effect of sub-soiling was detrimental. This indicates that Sub-soiling, as mentioned before, can increase the leaching of nutrients, such as nitrates. As for the acid effect, it has been proven, in a wheat crop, that N absorption improved when available sulfur increased in the soil, especially from the beginning of canopy or maximum growth stage.

4.3. Relative Sufficiency of N-NO_3 in Soil and N in Leaves (%)

The relative sufficiency (%) of nitrogen in both soils and leaves are being shown in Table 1. The information was based considering 20 ppm of N-NO_3 for soils and 2.7% for plants, given as the Critical Levels by the Mexican Official Standard (SEMARNAT, 2002) and Jones Jr. *et al.* (1973) respectively.

In the case of N-NO_3 the only treatments with the highest Relative Sufficiency, and above the Critical Level of 20 ppm were T3 (With Acid + Sub-soiling) and T4 (With Acid + No Sub-soiling) with 114.0% and 188.0% respectively.

In the case of acid treatments, the Sub-soiling showed a 14% of sufficiency vs. 88% with No Sub-soiling as compared to the Critical Level (a gap of 74%) whilst for treatments T1 (Without Acid + Sub-soiling) and T2 (Without Acid + No Sub-soiling) the gap of sufficiency was 6% only. In both cases the acid can mitigate the negative effect of Sub-soiling.

On the other hand, the same trend happened with the N foliar content. The same T3 and T4 showed the highest Relative Sufficiency with 92.5% and 96.9% respectively whilst the lowest, but similar values, were with T1 (91.1%) and T2 (90.7%).

4.4. Statistic Analysis

The Analysis of Variance (ANOVA), as a statistical method, to select the best treatment, (Table 2) did not show any statistical differences. However, a very good correlation was found between soil nitrates N-NO_3 (ppm) with N contents (%) in the plant as shown in **Figure 3** with a Coefficient of Determination (**r^2**) of 0.98.

The Coefficient of Determination (**r^2**) of 0.98 means a good relationship betwwen N-NO_3 in soils (ppm) and the N found in leaves (%). The positive effect of sulfuric acid and the negative effect of Sub-soiling were really reflected on the concentratión of N, in both soil and plant.

Table 1. Relative sufficiency (%) of nitrogen in soils and leaves as compared with the critical levels (SEMARNAT, 2002; Jones Jr. *et al.* 1973).

Treatments	**Soil N-NO_3 (ppm)**	**Relative sufficiency of N-NO_3 (%)**	**Foliar N (%)**	**Relative sufficiency of foliar N (%)**
T1 = Without Acid + Sub-soiling	16.4	82.0	2.46	91.1
T2 = Without Acid + No Sub-soiling	17.6	88.0	2.45	90.7
T3 = With Acid + Sub-soiling	22.8	114.0	2.50	92.5
T4 = With Acid + No Sub-soiling	37.6	188.0	2.60	96.9
Critical Level	20	100	2.70	100

Table 2. Mean squares from the Analysis of Variance (ANOVA) of Soil N-NO_3 and N in leaves.

Source of Variation	Degree of freedom	Soil N-NO_3 (ppm)	N in leaves (%)
Treatments	3	568.96 (NSD)	0.0244375 (NSD)
Replications	1	25.92 (NSD)	0.0015125 (NSD)
Error	3	68.16	0.0826375

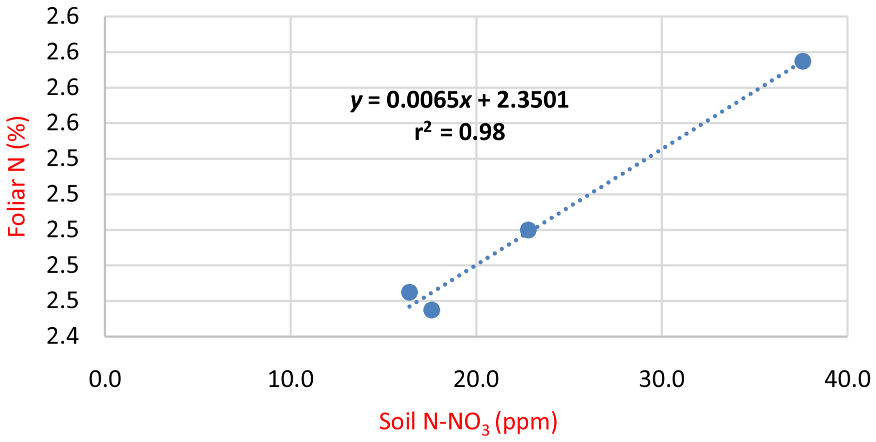

Figure 3. Relationship between soil N-NO_3 (ppm) (x) and N (%) in leaves (y) of Chichen Itza maize (*Nukuch Nah*). Note: NSD = No Statistical Differences (5%).

5. Conclusions

The red arable *rhodic Luvisols* of Yucatan Mexico, show high alkalinity problems, and at the same time have been exposed to a very high intensive corn cultivation with consequent soil compaction and negative collateral effects. In this work, acidification and subsoiling, alone or in combination, were tested to prevent the problem.

The main results suggest that:

1) The N-NO_3 in the soil were higher than the Critical Limit of 20 ppm when acid was applied.

2) When no acid was applied, the Nitrate was reduced below the critical range.

3) Regardless of the acid, the use of Sub-soiling reduced N-NO_3 in the soil

4) The N in leaves, of all treatments, were below the Critical Limit of 2.7%.

5) It is noteworthy that the N content was highest (2.6%) With Acid + No sub-soiling (T4) as compared to the lowest value (2.45%) Without Acid + Sub-soiling (T1).

6) The statistical analysis through the Analysis of Variance (ANOVA) suggested No estatistical differences among treatments.

7) A very good correlation was found between the N-NO_3 (ppm) in soil and N (%) in leaves with a Determination coefficient ($\mathbf{r^2}$) of 0.98.

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Conflicts of Interest

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

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