



# Effect of Acid and Sub-Soiling on Available Phosphorus in a Calcareous *Rhodic Luvisol* Planted with Two Corn Materials in Yucatan, Mexico

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**How to cite this paper:** Ramírez-Silva, J.H., Cano-González, A. and Uzcanga-Pérez, N.G. (2024) Effect of Acid and Sub-Soiling on Available Phosphorus in a Calcareous *Rhodic Luvisol* Planted with Two Corn Materials in Yucatan, Mexico. *Open Access Library Journal*, 11: e12153.

<https://doi.org/10.4236/oalib.1112153>

**Received:** August 23, 2024

**Accepted:** September 16, 2024

**Published:** September 19, 2024

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## Abstract

The optimal soil pH for maximum phosphorus (P) availability ranges from 6.0-7.0. When the pH values are alkaline, as in the case of the Yucatan Peninsula (YP), the availability of P, in its anionic form of  $\text{H}_2\text{PO}_4^-$  can be reduced when reacting with the cationic forms of calcium ( $\text{Ca}^{2+}$ ) or magnesium ( $\text{Mg}^{2+}$ ). Deficiencies have been documented in different soils of the YP, including the red *rhodic Luvisols*. These soils, in addition to show chemical constraints, are facing other disadvantages such as the underground compaction due to intensive use of machinery for corn and other cultivated crops. However, applying agricultural acids and sub-soiling could overcome the problem. In this work, the effect of sulfuric acid and sub-soiling on P availability in a *rhodic Luvisol* was assessed. Statistical differences were found between treatments and the P-Olsen contents as compared to the Official Mexican Standard were above the average ranges of 5.5 to 11 ppm. In *Chichen*, a significant increase of P in the *Rhizosphere* was observed with acid, and the highest level (44.4 ppm) was with no sub-soiling (T4). No acid but sub-soiling (T1) had the lowest level of P in *Chichen* (19.80 ppm). In contrast, in the *Hybrid* the acid induced a reduction of P contents, but with the same trend as *Chichen*, lower P when sub-soiling. Subsoiling itself, without acid application, can reduce P from 19% (*Hybrid*) to 25% (*Chichen*). Subsoiling can induce P losses by leaching since this practice increases the water infiltration.

## Subject Areas

Agricultural Engineering

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## Keywords

pH, Anionic Form, Deficiencies, Compaction

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## 1. Introduction

In both acidic and alkaline soils, the availability of phosphorus (P) is threatened by the formation of poorly soluble compounds. In acidic soils, phosphorus tends to react with Aluminum (Al), Iron (Fe) and Manganese (Mn), while, in alkaline soils, the dominant fixation is with Calcium (Ca). The optimal pH for maximum phosphorus availability is from 6.0 to 7.0.

Roots absorb phosphorus mainly in the form of primary ortho-phosphate ion ( $\text{H}_2\text{PO}_4^-$ ), or as a secondary ortho-phosphate ( $\text{HPO}_4^{2-}$ ). The pH strongly influences the amounts of P that the plant can absorb. High alkalinity can reduce the availability of ( $\text{H}_2\text{PO}_4^-$ ) since P reacts with calcium ( $\text{Ca}^{2+}$ ) in order to form a very low soluble Tricalcium Phosphate- $\text{Ca}_3(\text{PO}_4)_2$  [1].

At least 38 tropical countries in the world have reported significant P deficiencies. In the intensive grazing areas in the state of Quintana Roo in Mexico, deficiencies were found in different soils: *rhodic Luvisol*, *chromic Luvisol*, *Vertisols* and *rendzic Leptosols* with amounts, ranging for each soil, of 1.40 - 1.79, 1.61 - 2.07, 2.18 - 2.81 and 3.6 - 4.24 ppm respectively [2]. Any of these soils reached the optimum levels of 5.5 - 11.00 parts per million ( $\text{mg kg}^{-1}$ ) as compared with the Official Mexican Standard when using the Olsen Method to quantify available P (SEMARNAT, 2002) [3].

Linked to the findings in the state of Quintana Roo Mexico, in the Yucatán Peninsula (YP) [2] other authors have reported low P levels in both forage and soil of grazing areas [4].

On the other hand, the red arable *rhodic Luvisols* soils of Yucatan, in addition to their alkaline origin, present physical compaction problems related to more than 30 years of intensive use cultivated with corn and other crops. The negative effect of soil compaction is a problem that has been argued for corn field conditions in the corn strip of “Frailasca, Chiapaneca” in southern Mexico [5].

There are several works confirming the advantage of using acidic compounds, in calcaric soils, to increase the availability of different nutrients such as Nitrogen [6] and Zinc [7] but the same authors are arguing that sub-soiling [6] [7], per se, have a detrimental effect on nutrients availability of those specific nutrients, although there are others arguing the advantage to other nutrients.

Taking into account that:

Phosphorus (P) is a limiting nutrient in calcareous soils, due to the effect of Calcium (Ca) to form unavailable chemical forms such as  $\text{Ca}_3(\text{PO}_4)_2$ , which can be diluted to available forms by using acids; and that sub-soiling, at the same time, can improve nutrients availability when breaking up compacted soils; this work was proposed with the objective of assessing the effect of both acid and sub-soiling

in the availability of P in a *rhodic Luvisol* of Yucatan Mexico cultivated with corn variety *Chichen Iza* (Nukuch Nah) and the *Hybrid H-443A*.

## 2. Materials

### 2.1. Corn Materials and Treatments

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

Two genetic materials planted at 56,000 plants·ha<sup>-1</sup> were evaluated: variety *Chichen Itza* (*Nukuch Nah*) and the commercial *Hybrid H-443A*, both with yellow grain, subjected to the following eight treatments:

*T1* = Without Acid + Sub-soiling + *Chichen*

*T2* = Without Acid + No Sub-soiling + *Chichen*

*T3* = With Acid + Sub-soiling + *Chichen*

*T4* = With Acid + No Sub-soiling + *Chichen*

*T5* = Without Acid + Sub-soiling + *Hybrid*

*T6* = Without Acid + No Sub-soiling + *Hybrid*

*T7* = With Acid + Sub-soiling + *Hybrid*

*T8* = With Acid + No Sub-soiling + *Hybrid*

## 3. Methods

### 3.1. Soil Preparation, Basal Fertilization and Acid Application

The first preparation of the soil was carried out by using a semi-heavy harrow before sub-soiling the area. Sub-soiling was made by using a vertical chisel, plowing at a depth of 40 cm in order to break up the compacted underground layers.

A basal fertilization, at sowing, was with *Diammonium Phosphate* containing Nitrogen (*N*) at 18% *N* and Phosphorus (*P*) at 46% *P<sub>2</sub>O<sub>5</sub>* with no Potassium (*K<sub>2</sub>O*) buried 10 cm from the planted line. Drip irrigation was carried out every day but the sulfuric acid (*H<sub>2</sub>SO<sub>4</sub>*) at 98% concentration with agricultural quality was applied twice a week.

### 3.2. Experimental Design, Soil Sampling and Statistical Analysis

The eight treatments were distributed in a Completely Randomized Block Design with two replications; and in each experimental unit a composite sample of soil was taken. Each composite soil sample was formed by mixing six subsamples coming from the *rhizosphere* of six plants in complete competition.

The soil *P* content was determined by the Olsen method (mg·kg<sup>-1</sup> or ppm) according to Phytomonitor laboratories (2022) [8] and the results were subjected to an Analysis of Variance (ANOVA) and Comparison of Means (Tukey at 0.05) using the Statgraphic program.

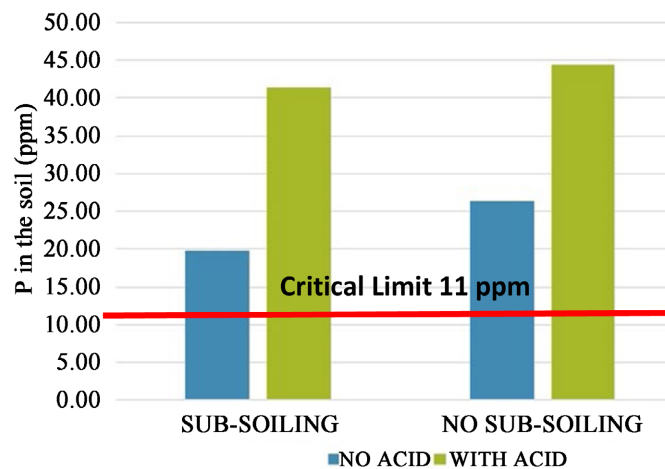
The means were compared with the reference levels given by the Official Mexican Standard (SEMARNAT, 2002) [3] classifying the *P* contents as Low: <5.5

ppm, Medium: 5.5 - 11 ppm and High > 11 ppm according to the Olsen extraction method.

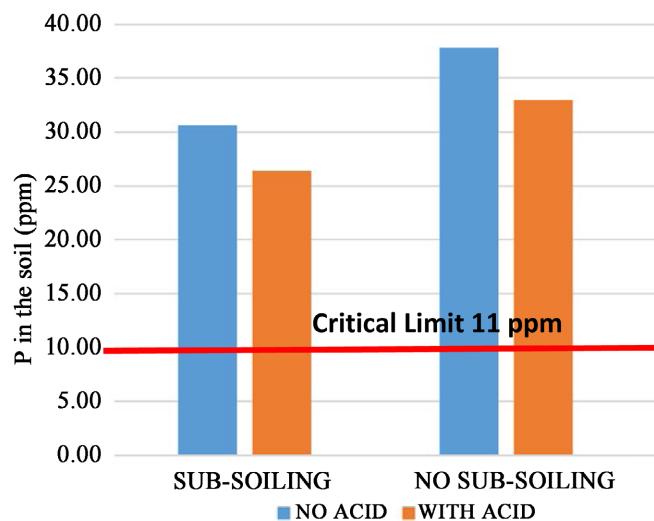
## 4. Results

### 4.1. Available Phosphorus in the Rhizosphere

The available P (ppm) in the *rhizosphere* of *Chichen Itza* and the *Hybrid-443A* corn are being shown in **Figure 1** and **Figure 2** respectively. All contents are above the optimal levels of 5.5 and 11.0 ppm proposed when P is extracted by Olsen method [3].



**Figure 1.** Phosphorus content (ppm) in the Rhizosphere of *Chichen Itza* variety in a *rhodic Luvisol* with sulfuric acid and sub-soiling.



**Figure 2.** Phosphorus content (ppm) in the Rhizosphere of the *Hybrid H-443A* in a *rhodic Luvisol* with sulfuric acid and sub-soiling.

However, in *Chichen* a significant increase of P was observed when applying acid, obtaining the highest level (44.4 ppm) when sub-soiling was used (T4). Not applying acid, but sub-soiling (T1) implied having the lowest P level in *Chichen*.

In contrast to *Chichen*, applying acid in the *Hybrid* was detrimental, but with the same trend as it was with *Chichen* when the P contents were reduced when sub-soiling, regardless of acid application. Sub-soiling by itself, without acid application, can reduce P from 19% (*Hybrid*) to 25% (*Chichen*).

On the other hand, the T2 and T6 referring to treatments Without Acid + No Sub-soiling in *Chichen* and the *Hybrid* respectively, named as the controls, showed significant contents of available P as compared to the 11 ppm of the Critical Level: 26.4 vs. 11 ppm for *Chichen* and 37.8 vs. 11 ppm for the *Hybrid*. Those highest contents are related to the residual effects of P fertilizers applied during the yearly intensive use of the soil and the basal application of P as *Diammonium Phosphate* at the beginning of the experiment.

#### 4.2. Statistical Analysis of P Contents in the Rhizosphere

The ANOVA of the treatments showed highly significant statistical differences with a  $p = 0.0375$  as is shown in **Table 1**.

**Table 1.** Comparison of means of assimilable P contents (ppm) in treatments related to the application of acid and sub-soiling in two corn materials.

Source of variation	Square Sum	Degree of freedom	Mean square	F	P
Between treatments	976.95	7	139.56	3.91	0.0375
Between replications	285.84	8	35.73		
Total	1262.79	15			

**Table 2.** Comparison of means of assimilable P contents (ppm) in treatments related to the application of acid and sub-soiling in two corn materials.

Treatments	Average	Relative percentage (%)	Statistically different groups (Tukey $\alpha$ 0.05)
T4 = With Acid + No Sub-soiling + <i>Chichen</i>	44.4	100.0	A
T3 = With Acid + Sub-soiling + <i>Chichen</i>	41.4	93.2	ABC
T6 = Without Acid + No-Sub-soiling + <i>Hybrid</i> (Control)	37.8	85.1	ABC
T8 = With Acid + No Sub-soiling + <i>Hybrid</i> .	33.0	74.3	ABCD
T5 = Without Acid + Sub-soiling + <i>Hybrid</i>	30.6	68.9	BCD
T2 = Without Acid + No Sub-soiling + <i>Chichen</i> (Control)	26.4	59.4	CD
T7 = With Acid + Sub-soiling + <i>Hybrid</i>	26.4	59.4	CD
T1 = Without Acid + Sub-soiling + <i>Chichen</i>	19.8	44.5	D

**Table 2** shows the comparison of means and different groups according to the statistic Fisher's least significant difference (LSD) procedure. Four homogeneous

groups have been identified according to the alignment of the same letters in the columns. There are no statistically significant differences between those levels that share the same column of letters. The T4 (letter A) stands out and is related to Acid + No sub-soiling + *Chichen Itza*, which with 44.4 ppm of P, in the rhizosphere, forms the first group together with T3, T6 and T8.

The second group (letter B) is led by T3 (Acid + Sub-soiling) followed by T6, T8 and T5. The third group with letter C is led by the same T3 and followed by T6, T8, T5, T2 and T 7. The fourth group with the lowest contents of P in the rhizosphere is led by T8 with 33 ppm followed by T5 (30.6 ppm), T2 (26.4 ppm), T7 (26.4 ppm) and T1(19.8 ppm). This late T1 (*Without Acid + Sub-soiling + Chichen*), even though it obtained the lowest P content, never reached the minimum critical level of 15 ppm suggested by the literature [3].

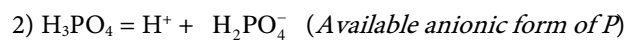
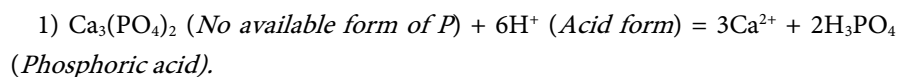
## 5. Discussion

It is likely that sub-soiling is triggering leaching losses of nutrients to deep soil horizons, out of the *rhizosphere*, since this practice improve water infiltration levels. It has been suggested [9] that nutrient contents can be modified when soil structure is improved by sub-soiling causing changes in chemical reactions such as the *Oxidation-Reduction* process (REDOX) and soil biochemistry.

Those chemical changes, which can also be disadvantageous, can be related to nutrient leaching, decomposition of organic matter and biological activity while humidity is reduced and cationic relationships are modified.

It has been reported [9], as in our case, that nutrients such as P, as well as Calcium (Ca) and magnesium (Mg) can be diminished when sub-soiling whilst potassium (K), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) can be enhanced.

On the other hand, Sulfuric acid ( $\text{H}_2\text{SO}_4 \rightarrow 2\text{H}^+ + \text{SO}_4^{2-}$ ), in the soil, can solubilize compounds with iron and zinc, as well as Mn, Ca and P, by lowering the pH when the numbers of Hydrogens ions ( $\text{H}^+$ ) increased in the soil solution and dilute the  $\text{Ca}_3(\text{PO}_4)_2$ . The chemical related process, for P availability, can be explained by the next reactions:



The acid can also improve structure and infiltration rate Calcium (Ca) and magnesium (Mg) [10]. However, the solubility of various elements, due to the acid, can cause antagonistic effects [11]. An appropriate management strategy has to do with detailed knowledge of the physical and chemical properties because failure to do so can exacerbate plant nutrition problems.

On the other hand, it is important to mention that in, an opposite way, in acidic soils with low pH, the Aluminum in its cationic form ( $\text{Al}^{3+}$ ), instead of  $\text{Ca}^{2+}$ , is the main cause of the low P availability by forming ( $\text{AlPO}_4$ ); and that is the reason why Lime is applied, as Calcium Carbonate ( $\text{CaCO}_3$ ) to enhance P availability [12].

## 6. Conclusions

When the pH values are alkaline, as in the case of the Yucatan Peninsula (YP) in Mexico, the availability of P, in its anionic form of  $\text{H}_2\text{PO}_4^-$  can be reduced when reacting with the cationic forms of calcium ( $\text{Ca}^{2+}$ ) or magnesium ( $\text{Mg}^{2+}$ ). Deficiencies have been documented in different soils of the YP, including the red *rhodic Luvisols*. Other problems facing are related to the underground compaction due to intensive use of machinery when cultivating corn and other crops. However, applying agricultural acids and sub-soiling could overcome the problem.

The results of this work coincide with those of other authors, mainly on the advantage of using acid but no in the constraining effects of sub-soiling in the availability of phosphorus (P).

1) Highly statistical differences were found between treatments and the P-Olsen contents compared to the ranges of the Mexican Official Standard were above the average ranges of 5.5 to 11 ppm.

2) In *Chichen Itza (Nukuch Nah)*, a significant increase of P was observed when applying acid, obtaining the highest level (44.4ppm) but without sub-soiling (T4).

3) Without acid but sub-soiling (T1) the lowest level of P in *Chichen* was obtained.

4) Contrary to what happened in *Chichen*, in the *Hybrid* the acid decreased the P contents in the *Rhizosphere*, but with the same trend, as in the *Chichen*, when the P contents was reduced by sub-soiling.

5) Sub-soiling by itself, without acid application, can reduce P from 19% (*Hybrid*) to 25% (*Chichen*). It is likely that sub-soiling is activating leaching losses to deep horizons since this practice increases water infiltration.

## Acknowledgements

We thank the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) of MEXICO for financing this work, as part of the project: *Technological Components for Sustainable Corn Production in the State of Yucatan*.

## Conflicts of Interest

The authors declare no conflicts of interest.

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