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ORIGINAL ARTICLE

Comparative Study of Four Techniques for the Labile Phosphorus Extraction and Critical Level for Corn Growth in Vertisols

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ABSTRACT
In this research, the correlation and calibration of four extraction techniques for available phosphorus were studied: Soltanpour and Schwab, North Carolina, Olsen and Bray P_1 in six soils classified as Vertisols of the municipalities of Jiquilpan, Venustiano Carranza, Villamar, and Pajacuaran in the Cienega de Chapala, Michoacan, Mexico. The aim of this work was to select an extraction technique for available phosphorus that evaluates the availability of this nutrient, and critical level for corn H-303 variety phosphoric fertilization. A completely random design with four levels of phosphorus (00, 300, 600, and 1200 mg kg^{-1} of soil) and four replicates was used. The dry matter yield, relative yield, and phosphorus uptake for corn plants were evaluated. The phosphorus critical levels by four analytic techniques using the graphic and mathematical procedures were determined. The phosphorous critical level by Olsen technique was 38 mg kg^{-1} of soil, 38 mg kg^{-1} of soil by Bray P_1 technique, 6 mg kg^{-1} of soil by Soltanpour and Schwab technique, and 270 mg kg^{-1} of soil by North Carolina technique. The best extraction techniques to determine available phosphorus were the Olsen and Bray P_1 techniques, with critical levels of 43 and 56.2 mg kg^{-1} of soil, respectively.
Kay words: Soil phosphorus, Soltanpour and Schwab, North Carolina, Olsen, Bray P_1.

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INTRODUCTION

The phosphorus, as an essential element for plant growth, possibly has a more complex dynamic in soil. Different techniques have been developed for its extraction in plant available forms; the dynamic has been studied in different soil types, finding that phosphorus behavior depends on management, and specific chemical, and physicochemical conditions [1]. In acid soils it has been found in the orthophosphoric available forms ($H_2PO_4^{1-}$ and HPO_4^{2-}) [2], while in alkaline ones, in the HPO_4^{2-} and PO_4^{3-} forms. In some cases the phosphorous is retained by cations such as Al^{3+}, Fe^{3+}, Ca^{2+} etc.; consequently, the quantity of its available forms to plants growth ($H_2PO_4^{1-}$, HPO_4^{2-}, and PO_4^{3-}) can diminishing significantly [3].

Different techniques for labile phosphorus extraction for each soil type, considering the influence of the buffer solution ions on the chemical forms that affect the dynamics of this nutrient have been development. As in the case of Bray P_1 solution [4] consisting of a solution of NH_4F 0.025N + HCl 0.03N based on the solubilizing action of H^+ on soil phosphorus and the characteristic of the fluoride ion to reduce the activity of the aluminum ion, avoiding thus, the reabsorption of orthophosphoric available forms in the extraction system [5, 6].

Knowledge of the different chemical forms of soil phosphorus, which contribute to the agricultural crops nutrition, facilitates the selection of the extractant solution to estimate the content of soil labile phosphorus; also must be considered their correlation degree with the plant response to the phosphoric fertilization treatment. If it wants the analysis system be reliable, the yield response to the applied doses of the nutrient may be related to the available quantity of phosphorus in the soil, through calibration with crop growth under field conditions, where interacting the factors like soil-climate-plant [7-11].

In relation to chemical techniques for the soil extractable phosphorus analysis, several authors [12], who through the years, have done research on this tenor; in general, they have developed and applied extracting solutions. These extracting solutions are composed with organic and inorganic acids, including various types of anions (citrates, fluorides, chlorides, acetates, arsenates, oxalates, sulfates, etc.) which form stable ionic complexes with phosphorus, releasing it in much larger quantities than it is actually taken up by the plants. On the other hand, they have reported that different solutions, extract different quantities of soil labile phosphorus, which involves a problem for technicians who perform tests for diagnosis and recommendation for management of soil fertility.

Several of the labile phosphorus extractant solutions generated by the researchers involved in soil chemistry, have been used to estimate the labile phosphorus from agricultural soils, with the news that the results of the analysis included interpretation. Unfortunately, this was of an insufficient degree of objectivity to make a quantitative recommendation of phosphoric fertilizers, talking about a likely response of the crops to the phosphoric fertilizers application [13-15].

Considering the chemical properties of the Olsen solution, this has been used for labile phosphorus extraction of the soil organic matter light fraction, resulting in a positive correlation between these two variables [16] and it has been concluded that an increase of phosphorus in the soil organic matter light fraction, favors its immediate availability. However, other researchers [17] did not find an increase in the extractable phosphorus with the Olsen solution [14], but with a NaOH solution, they found increase in the phosphorus content of the soil organic matter light fraction.

More objective studies related to the level estimation of labile phosphorus in agricultural soils for phosphoric fertilization recommendation, have been made in the last 50 years in different parts of Mexico and Central America. In most of the research conducted in different soils about comparing of different techniques for the labile phosphorus extraction from agricultural soils, those that have given the highest correlation coefficients and greater significance are the Olsen and Bray P_1 extractant solutions [18-24].

The aim of this study was to select a soil labile phosphorus extracting solution and correlate it with corn H-203 variety production in greenhouse and field calibration to select its critical level and diagnose the corn phosphoric fertilizer required in soils from the Cienega de Chapala, Michoacán, Mexico.

MATERIALS AND METHODS

Sampling Sites and Soil Analysis

Soils from the localities of La Palma, Cumuatillo, Cuatro Esquinas, San Gregorio, Emiliano Zapata, and Jiquilpan from the Cienega de Chapala, Michoacan, Mexico, were selected using the map of physiographic units [25]. The samples were taken at a depth of 0 to 20 cm and mixed to derive a composite one of each soil. Employing soil laboratory routine techniques, the physically and chemically characterization of soils were made. The pH was determined with potentiometric technique in a 1:2 ratio (soil: water). Soil texture was determined with the Bouyoucus hydrometer technique [26]. The organic matter (OM) content in soil was determined by the Walkley and Black technique [27]. The soil phosphorus retention capacity (PRC) was estimated by Caudillo and Quiñones method (1973) [28]. Finally, using the soil column method proposed by Aguilera and Martinez (1986) [29], the field capacity (FC) of each soil was determined.

Extractant Techniques and Selection

Two acid and two alkaline extractant solutions were compared, the first ones were the North Carolina extractant solution prepared with HCl 0.05N + H_2SO_4 0.025N [10] and, the Bray P_1 extractant solution prepared with HCl 0.025N + NH_4F 0.03N [4]. The second ones were the Olsen extractant solution prepared with $NaHCO_3$ pH 8.5 [14] and the Soltanpour and Schwab extractant solution prepared with NH_4HCO_3 + DTPA, pH = 7.6 [15]. To select the best extractant solution of labile phosphorus in the Vertisols, coefficients of simple correlation among the variables of response and phosphorus extracted by different techniques were estimated.

Greenhouse work

In a greenhouse a completely randomized experimental design with four levels of phosphorus (00, 300, 600 and 1200 mg kg-1) and four replicates was used. Six liters of Soil with their respective phosphorus treatments, in plastic pots were placed, in each pot one corn H-303 seed variety was planted, and soil moisture at 80% of its field capacity during the research was maintained. The corn plants were harvested at 60 days and dried in an oven at 75°C until constant weight was obtained, then, ground was sieved through a 1 mm mesh and were weighed; total phosphorus by the C vitamin technique [30] was determined.

Critical Levels

Using the labile phosphorus extracted with each technique as independent variable, and the relative yield obtained from field data [32] as dependent variable, the phosphorus critical levels were obtained by the graphical procedure [31] and the mathematical procedure [32]. These allow interpreting the labile phosphorus analysis, as it represents the threshold concentration of the nutrient in the soil, below which requires the application of phosphoric fertilizer for optimum corn yield.

Statistical Analysis

Linear regression analysis were performed, using as independent variable extracted phosphorus with each extractants solutions, and as independent variable, the control yield, fertilized treatment yield, relative yield, control phosphorus uptake, and additional phosphorus uptake [33].

RESULTS AND DISCUSSION

The soil analysis indicated two interesting aspects, one is that in all cases they are clayey soils, and the second one is that they have a high phosphorus retention capacity (PRC), making it more interesting this research. On the other hand, organic matter (OM) contents vary from medium to low; with the exception of La Palma soils, all they are slightly acidic, with high field capacity (FC) and high phosphorus contents (Table 1).

The different extractant solutions, significantly influenced on extracted labile phosphorus from soils of the Cienega de Chapala with different treatments. For instance, with the Soltanpour and Schwab technique [15], the extracted phosphorus quantities of control, varied between 2.0 and 4.0 mg kg-1 of soil; while with the North Carolina technique [10], the values ranged from 208 to 400 mg kg-1 of soil respectively (Table 2).

The extracted phosphorus quantity by the Soltanpour and Schwab technique [15], was too low, even with the application of 1200 mg kg^{-1} of P_2O_5, which means that the extractant solution based on NH_4HCO_3 is little effective. Consequently, it does not have the strength to dissolve the available phosphorus forms to plants. In addition, according to the soil physicochemical conditions, which under periodic flooding to which they are subjected every year, the Fe^{2+} form complex amorphous compounds, so these soils have a high capacity to retain phosphorus [34], being the San Gregorio, Cuatro Esquinas and Cumuatillo soils, those with the highest retention capacities: 83.25, 83.24 and 80.1% of retention, respectively. On the contrary, with the North Carolina extractant solution based on HCl 0.05N + H_2SO_4 0.025N [10], and due to its high acidity, the available phosphorus extraction is very high. Accordingly, this solution is extracting the phosphorus of both, mineral and organic components that do not become available for crops immediately. However, when 1200 mg kg^{-1} of P_2O_5 is applied, the solution extracts less than 50% of this, reinforcing the view that these soils have high phosphorus retention capacity (Table 1).

By linking the extracted phosphorus by each techniques with dry matter yields and taken up phosphorus by corn plants, the corresponding correlation coefficients were obtained, which have different magnitude, indicating that the soils have differences in their physical and chemical characteristics, so that the efficiency of the different techniques for the labile phosphorus extraction are different (Table 3)

Soltanpour and Schwab technique [15], showed significant correlation coefficients at 5% for both variables (corn dry matter yield and corn plants phosphorus uptake), indicating that the extracted ortophosphoric fractions were related with the corn response to phosphoric fertilizer applications and with plant taken up forms. On the contrary, the correlation coefficients obtained by the North Carolina technique [10], Olsen [14] and Bray P_1 [4], were not significant, which means that the amount of extracted phosphorus are not related to the plant response to the phosphoric fertilization or uptake of this nutrient.

The Soltanpour and Schwab [15] and North Carolina [10] techniques had significant correlation coefficients, both at 5% and 1% with the control yield, fertilized treatment yield, relative yield and the yield increase, indicating that these extracted phosphorus quantities are related with the yield in the studied soils. However, the correlation coefficients between the extracted phosphorus with these techniques and phosphorus uptake and additional phosphorus uptake were not significant (Table 4).

Olsen [14] and Bray P_1 [4] techniques showed significant simple correlation coefficients at 5% with control yield and fertilized treatment with the control treatment phosphorus uptake, but gave highly significant correlation coefficients with additional phosphorus uptake, indicating that the extracted phosphorus was related with the yield and phosphorus uptake. In addition, Bray P_1 technique [4] showed a highly significant simple correlation coefficient with control yield.

The high correlations obtained between extracted phosphorus with the Olsen technique [14] and the dry matter production of the fertilized treatment and taken up phosphorous, are consistent with the results obtained by Cajuste et al, (1995) [22]. This technique has been effective for the labile phosphorus extraction from alkaline soils, as the HCO_3^- is quite effective to replace the adsorbed phosphorus, and high OH^- concentration reduce the Ca^{++} activity in solution becoming free for phosphorus extraction.

Again, it is seen that Soltanpour and Schwab [15] and Bray P_1 [4] techniques gave the highest significant correlation coefficients at 5% between the extracted phosphorus and control dry matter yield. Also shows that the different techniques had significant correlation coefficients at 5% and 1% between the extracted phosphorus and the fertilized treatment yield, so it can be said that there is a close relationship between these variables.

Although the quantity of extracted phosphorus by the Soltanpour and Schwab [15] technique was very low and that the extracted with the North Carolina technique was too high, they had a significant correlation coefficient at 5%. However, the chemical forms in which plants absorb phosphorus are $H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-} and considering that the plants taken up much larger quantities than those determined with the Soltanpour and Schwab [15] technique, and if the extracted phosphorus by the North Carolina [10] technique were real, should be antagonistic effects with other nutrients as Fe^{2+}, Zn^{2+} among other in the rhizosphere, but as the corn plants did not manifest any type of nutrition problem, it is not possible to select these techniques as the most appropriate for analyzing the labile phosphorus in the studied soils.

In relation to the comparison of Soltanpour and Schwab [15] vs Bray P_1 [4], North Carolina [10] vs Olsen [14], North Carolina [10] vs Bray P_1 [4] and Olsen [14] vs Bray P_1 [4] techniques, no significant correlation coefficients were found. The quantities of extracted phosphorus with Olsen [14] and Bray P_1 [4] extractant solutions had mean values and were related to each other by giving significant correlation coefficients at 5%.

With the phosphorus concentrations estimated by the different extracting techniques and relative yields, critical levels that allow the analysis interpretation of this nutrient in the soils of the Cienega de Chapala were obtained (Table 5, Figures 1 and 2).

When the correlation coefficients between phosphorus extracted by each techniques studied with the different statistical models, it was concluded that the linear model is the most suitable (Table 6). The correlation coefficients obtained between the Soltanpour and Schwab [15] and North Carolina [10] techniques were significant at 1% and 5% respectively. In the same way, the correlation coefficient between the North Olsen [14] and Bray P_1 [4] techniques was significant at 5%.

The Olsen [14] and Bray P_1 [4] techniques were considered the best because of its high correlation coefficient with the different response variables. It was observed that 65% of the points remained in the positive quadrant, indicating that in general the Vertisols of the Cienega de Chapala are high in phosphorus. Consequently, 35% do not response to phosphoric fertilization, so that it is reassert its high efficiency to estimate the labile phosphorus in these soils.

The critical level determined by the graphical [31] and mathematical [32] procedures for Olsen [14] and Bray P_1 [4] techniques (Table 5) were of 38.0 and 40.0 mg kg^{-1} of phosphorus respectively, and both showed a 95.0% similarity.

Table 1. Soil characteristics of six localities of the Cienega de Chapala, Michoacán, Mexico

Localities	Textural Class	OM[1] (%)	pH	FC[2] (%)	P mg kg^{-1}soil	PRC[3] (%)
Cuatro Esquinas	Clayey	1.8	6.9	45	34	80.1
La Palma	Clayey	1.8	8.6	39	40	74.28
San Gregorio	Clayey	3.6	6.8	44	28	83.25
Emiliano Zapata	Clayey	1.2	6.5	44	36	75.37
Jiquilpan	Clayey	0.9	6.9	46	32	75.67
Cumuatillo	Clayey	1.6	6.7	41	25	83.24

1. OM: Organic Matter; 2. FC: Field Capacity; 3. PCR: Phosphorous Retention Capacity

Table 2. Labile phosphorus extracted (mg kg^{-1} of soil) from soils of six localities of the Cienega de Chapala with the different extractant techniques

Localities	Extractant techniques															
	Soltampour and Schwab				North Carolina				Olsen				Bray P_1			
PT[1]	0	300	600	1200	0	300	600	1200	0	300	600	1200	0	300	600	1200
Cuatro esquinas	2	2	3	7	210	205	220	300	34	41	44	66	33	75	90	139
La Palma	2	2	3	7	200	203	220	290	40	44	57	78	62	92	116	153
San Gregorio	4	4	5	10	400	430	520	600	28	30	36	56	17	50	64	117
Emiliano Zapata	2	3	3	6	210	230	262	295	36	42	45	62	23	47	75	106
Jiquilpan	3	4	4	7	320	350	385	408	32	32	39	56	28	66	81	115
Cumuatillo	2	3	5	7	208	220	256	281	25	35	37	58	24	62	83	135

1. PT: Phosphorous treatments (mg kg^{-1} of soil)

Table 3. Correlation coefficients between the soils extracted phosphorus by different techniques, the dry matter production and the phosphorus taken up by the plant

Response Variable	Phosphorous extraction techniques			
	Soltampour and Schwab	North Carolina	Olsen	Bray P_1
Dry Matter production (g $plant^{-1}$)	r = 0.6028	r = 0.5176	r = 0.3982	r =0.3823
Taken up Phosphorus (mg kg^{-1} of soil)	r = 0.8808	r = 0.3468	r = 0.3090	r = 0.0412

Table 4. Correlation coefficients between the extracted phosphorus of soil by the different studied techniques and the six response variables

Response variable	Phosphorous extraction techniques			
	Soltampour and Schwab	North Carolina	Olsen	Bray P_1
Control Yield	r = 0.811	r = 0.756	r = 0.390	r = 0.813
FTY[1]	r = 0.954	r = 0.814	r = 0.673	r = 0.675
Relative yield (%)	r = 0.760	r = 0.717	r = 0.386	r = 0.303
Yield increase	r = 0.837	r = 0.775	r = 0.465	r = 0.416
CPU[2]	r = 0.098	r = 0.243	r = 0.662	r = 0.725
APU[3]	r = 0.377	r = 0.142	r = 0.878	r = 0.806

1. FTY: Fertilized treatment yield; 2. CPU: Control phosphorous uptake; 3. APU: Additional phosphorous uptake.

Table 5. Critical levels (mg kg-1 of soil) for corn H-303 variety, determined with the extracted available phosphorus by the different techniques studied.

Procedure	Phosphorous extraction techniques			
	Soltampour and Schwab	North Carolina	Olsen	Bray P_1
Graphic	6.00	270.0	38.0	38.0
Mathematical	6.50	290.0	40.0	40.0
Similarity	92.30	93.10	95.0	95.0

Table 6. Correlation coefficients obtained between phosphorus extracted by each of the studied techniques with three statistical models.

Techniques compared	Mathematical model		
	Linear	Logarithmic	Quadratic
Soltanpour & Schwab *vs* North Carolina	r = 0.681*	r= 0.689*	r= 0.681*
Soltanpour & Schwab vs Olsen	r = 0.406	r= 0.465	r= 0.483
Soltanpour & Schwab vs Bray P_1	r = 0.144	r = 0.187	r = 0.148
North Carolina vs Olsen	r = 0.251	r = 0.296	r = 0.347
North Carolina vs Bray P_1	r = 0.391	r = 0.384	r = 0.391
Olsen vs Bray P1	r = 0.746	r = 0.708	r = 0.905

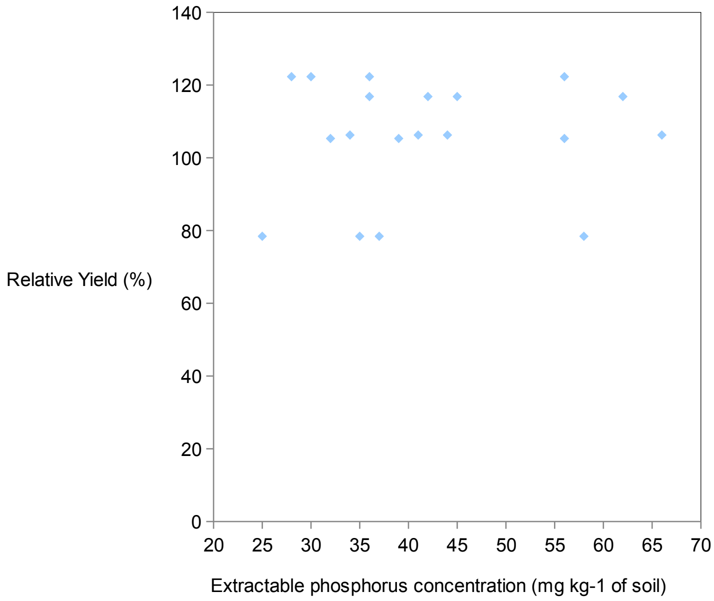

Figure 1. Critical level obtained by graphical and mathematical procedures for extractable phosphorus by the Olsen technique [14]

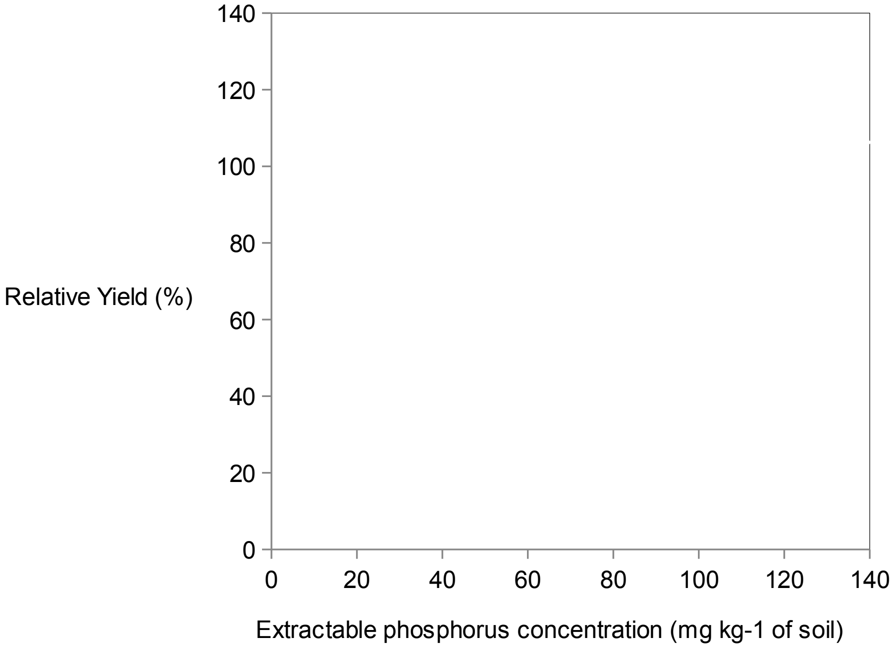

Figure 2: Critical level obtained by the graphical and mathematical procedures for extractable phosphorus by the Bray P1 technique [4]

CONCLUSSIONS

The recommended techniques to analyze the soil labile phosphorus for the H-303 corn variety crop in the Cienega de Chapala are: Bray P_1 [4] with a critical level of 56.2 mg Kg^{-1} and Olsen [14] with a critical level of 43.00 mg Kg^{-1} of soil respectively.

When determining the critical level for H-303 corn variety with the Olsen [14] and Bray P_1 [4] techniques, using the graphical and mathematical procedures, in both techniques a similarity of 95.0% was found.

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