

## Influence of Some Organic Acids on Availability and Adsorption of Phosphorus as well as Corn Growth in A Clay Soil

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**ABSTRACT:** Hypotheses that have been tested for this study are the effects of some organic acids on availability and adsorption of phosphorus (P) in clay soil as well as corn growth and phosphorus uptake. In a pot experiment the used organic acids [citric, tartaric and their mixture at ratio of 1:1 (w/w)], were added to soil at levels of 0, 0.2, 0.5 and 1% (w/w). This experiment was arranged in a randomized complete design with three replicates and planted by corn. The results obtained in this study reveal that organic acids addition significantly reduced P availability (Olsen-P) from 11.9 mg kg<sup>-1</sup> for control to 8.0 mg kg<sup>-1</sup> at 0.5 % level of citric and mixture of citric and tartaric acids. The maximal adsorption capacity of phosphorus (*b*) significantly increased with additions of organic acids. Applying mixture of citric and tartaric acids increased significantly sorption intensity constant (*n*). A significant increase of the sorption capacity constant (*K<sub>f</sub>*) happened with mixed citric and tartaric acids at all concentrations. But, adding 1% citric acid and 1% tartaric acid to clay soil caused significant decreases in *K<sub>f</sub>* parameter of phosphorus. The fresh weight of corn and P uptake were enhanced significantly with the addition of organic acids.

**Keywords:** phosphorus availability, citric, tartaric, sorption intensity, phosphorus sorption

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## INTRODUCTION

Organic acids play an important role in the soil as they affect the processes of minerals dissolution, complexation, and ion exchange. The limited availability of phosphorus (P) is a major worldwide problem in the acidic or alkaline soils. So, we always tend to study the factors that improve phosphorus uptake by plants. The availability of nutrients in soils especially phosphorus may be greatly affected by organic acids existed in the soil solution (Ström, 1997). Many organic acids in the soil solution can be identified, such as formic, acetic, oxalic, tartaric and citric acids due to the secretions of the roots, the activity of micro-organisms and decomposition of organic matter (Strobel, 2001; Sposito, 2008). The total concentration of organic acids in the soil solution ranges between 0.01 to 5 mol m<sup>-3</sup> and they are produced continually throughout the life cycles of microorganisms and plants (Sposito, 2008) as well as the variable concentrations of organic acids in the soil solution depending on soil properties and the conditions surrounding the extraction of organic acids from the rhizosphere (Jones *et al.*, 2003; Mimmo *et al.*, 2008). Low-molecular-weight organic acids and their released protons have major mechanisms controlling the dissolution, complexation, hydrolysis and exchange reactions with the soil's solution and solid phases (Jones and Darrah, 1994). The addition of organic acids to some soils reduced sorption and increased phytoavailability of phosphorus in soils (Hue, 1991). In the existence of organic acids, the adsorption of phosphorus depends on the concentration and type of the organic acid, pH, nature of the adsorbent and the background electrolyte (Violante and Gianfreda, 1995; Guppy *et al.*, 2005). Citrate anions affects phosphorus

availability attributed to some factors such as the mineral constituents, PO<sub>4</sub> loading, pH, citrate concentration and soil solution composition (Hu *et al.*, 2001; Ström *et al.*, 2002; Oburger *et al.*, 2011). The target of this study was to examine the effects of two organic acids (citric, tartaric) and their mixture at different levels on the release, removal efficiency and predicted maximum adsorption of phosphorus as well as growth of corn plant and P uptake in a clay soil.

## MATERIALS AND METHODS

### Pot experiment:

A pot experiment was conducted to study the effect of two organic acids on adsorption and the availability of phosphorus as well as corn growth in a clay soil. Surface soil samples (0-30 cm) were collected from the experimental Farm of Assiut University, Assiut, Egypt. The mineralogical composition of clay fraction consists of smectite clays which is common, kaolinite, mixed mica-smectite, vermiculite, sepiolite, palygorskite, chlorite, mixed mica-vermiculite, micas and pyrophyllite (Farragallah and Essa, 2011). The properties of this soil are given in Table (1). Soil samples were air-dried and crushed to pass through a 2-mm sieve before performing the chemical analysis and conducting the pot experiment. Plastic pots were filled with 3 kg of the air-dried soil. The organic acids used in this experiment were citric acid (CA), tartaric acid (TA) and a mixture of citric and tartaric acids (CA+TA) at ratio of 1:1 (w/w). They were added to the soil at levels of 0, 0.2, 0.5 and 1% (w/w). This experiment includes ten treatments as follows: Control, 0.2 % CA, 0.5 % CA, 1 % CA, 0.2 % TA, 0.5 % TA, 1 % TA, 0.2 % CA+TA, 0.5 % CA+TA and 1 % CA+TA. The soil was mixed with organic acids before planting. Ten Corn grains (*Zea mays*) were planted in each pot on April 13, 2016 and after germination the plants in each pot were thinned to four plants. The experimental design for this experiment was a completely randomized design with three replications. The nitrogen fertilizer was added at level of 0.6 g ammonium nitrate (33.5 % N) per pot in two doses. The corn plants in each pot were harvested after 37 days from planting and the total green yield and total dry matter were estimated. Samples of plant dry matter were finely ground for total phosphorus determination. Soil samples were also taken from all pots after harvesting and prepared for analysis. Phosphorus uptake by corn plants was calculated according to the following equation:

$$\text{Phosphorus uptake (mg pot}^{-1}\text{)} = \frac{\text{concentration of P in dry matter (mg kg}^{-1}\text{)} \times \text{dry matter (g pot}^{-1}\text{)}}{1000}$$

### Chemical analysis:

Available phosphorus (Olsen-P) in soil samples was extracted using 0.5 M NaHCO<sub>3</sub> at pH 8.5 according to Olsen *et al.* (1954), then it was determined colorimetrically using the chlorostannous phosphomolybdic acid method as described by Jackson (1973). Soil organic matter (OM) was determined by the modified Walkley and Black method. Soil pH was measured with a glass electrode using a 1:1 suspension of a soil to water ratio. Electrical conductivity (EC) was measured in a 1:2.5 of a soil to water extract using an electrical conductivity meter (Jackson, 1973). Soluble cations were determined in the soil

extract (1:2.5) according to Hesse (1998). Exchangeable cations were measured in the soil, using ethyl alcohol for removal of soluble cations from the soil prior to the extraction of the exchangeable cations. Exchangeable cations were replaced by  $\text{NH}_4^+$  using 1 M ammonium acetate solution at pH 7 (Baruah and Barthakur, 1997). Soluble and exchangeable cations such as calcium (Ca) and magnesium (Mg) were titrated using EDTA solution (ethyline-diamine tetra acetic acid), while sodium (Na) and potassium (K) were determined using the flame photometry method (Hesse, 1998). Particle-size distribution was measured using the pipette method. Total phosphorus in plants has been appreciated by the digestion of the samples with a 2:1 of  $\text{HNO}_3:\text{HClO}_4$  acid mixture. The phosphorus in the digest was determined colorimetrically using the chlorostannous phosphomolybdic acid method as described by Jackson (1973).

**Table (1). Some physical and chemical properties of the investigated soil**

| Property   | Value |
|--|-------|
| Clay ( $\text{g kg}^{-1}$ )                              | 474   |
| Silt ( $\text{g kg}^{-1}$ )                              | 306   |
| Sand ( $\text{g kg}^{-1}$ )                              | 220   |
| Texture  | Clay  |
| Organic carbon ( $\text{g kg}^{-1}$ )                    | 10.98 |
| pH (1: 1)  | 7.52  |
| EC (1:2.5) $\text{dS m}^{-1}$                            | 1.73  |
| Soluble Cations in soil extract                          |       |
| Ca ( $\text{cmol}_c \text{ kg}^{-1}$ )                   | 1.33  |
| Mg ( $\text{cmol}_c \text{ kg}^{-1}$ )                   | 0.83  |
| Na ( $\text{cmol}_c \text{ kg}^{-1}$ )                   | 2.17  |
| K ( $\text{cmol}_c \text{ kg}^{-1}$ )                    | 0.04  |
| Exchangeable Cations                                     |       |
| Ca ( $\text{cmol}_c \text{ kg}^{-1}$ )                   | 49.5  |
| Mg ( $\text{cmol}_c \text{ kg}^{-1}$ )                   | 19.56 |
| Na ( $\text{cmol}_c \text{ kg}^{-1}$ )                   | 2.17  |
| K ( $\text{cmol}_c \text{ kg}^{-1}$ )                    | 1.15  |
| $\text{NaHCO}_3$ - extractable P ( $\text{mg kg}^{-1}$ ) | 13.56 |

#### Adsorption isotherm:

Soil samples taken after corn harvesting were used for determination of phosphorus adsorption isotherm according to (Zhang *et al.*, 2009). One gram of air-dried soil samples was placed in the polypropylene centrifuge tubes and mixed with 20 mL of 0.02 M potassium chloride solutions (background electrolyte) containing 10, 20, 50 and 100  $\text{mg L}^{-1}$  phosphorus as  $\text{KH}_2\text{PO}_4$ . The tubes were shaken for 24 h. Then, the supernatants were filtered. The phosphorus concentration in the supernatant was measured colorimetrically by the chlorostannous phosphomolybdic acid method in sulphuric acid system (Jackson, 1973). At the equilibrium, the adsorbed amount of the phosphorus (Q) on the soil ( $\text{mg kg}^{-1}$ ) was found by Eq. (1) as well as the sorption efficiency (%) was calculate by Eq. (2) according to (Amin and Selmy, 2017).

$$Q = [(C_i - C_e) \times V]/m \dots\dots\dots(1)$$

$$\text{Sorption efficiency (\%)} = [(C_i - C_e)/C_i] \times 100\dots\dots\dots (2)$$

Where,  $C_i$  ( $\text{mg L}^{-1}$ ), initial concentration of phosphorus and  $C_e$  ( $\text{mg L}^{-1}$ ) is the equilibrium liquid-phase concentration of the phosphorus,  $V$  (mL) is the volume of the solution, and  $m$  (g) is the mass of the soil.

The Data of adsorption isotherms were analyzed by using Langmuir and Freundlich equations (Bohn *et al.*, 2001). The adsorption isotherms are important in determining the adsorption capacity of phosphorus by clay soil under organic acids applications.

Linear form of Langmuir Equation:

$$C/Q = 1/(kb) + C/b \dots\dots\dots (3)$$

By plotting  $C/Q$  vs  $C$ , the slope is  $1/b$  and the intercept is  $1/kb$ .

Linear form of Freundlich Equation:

$$\log Q = 1/n \log C + \log K_f \dots\dots\dots (4)$$

By plotting  $\log Q$  vs  $\log C$ , the slope is the value of  $1/n$  and the intercept is equal to  $\log K_f$ .

Where:  $C$  = equilibrium solution phase concentration of the phosphorus ( $\text{mg l}^{-1}$ ),  $Q$  = equilibrium solid phase concentration of the phosphorus or amount of P sorbed by soil ( $\text{mg kg}^{-1}$ ),  $b$  = Langmuir isotherm maximum sorption capacity ( $\text{mg kg}^{-1}$ ),  $k$  = the energy of sorption or bonding energy ( $\text{L mg}^{-1}$ ).  $n$  = sorption intensity constant, and  $K_f$  = sorption capacity constant ( $\text{L kg}^{-1}$ ). The maximum phosphorus buffering capacity (MPBC) was calculated by multiplying sorption coefficients  $b$  and  $k$  (Xu *et al.*, 2014).

**Statistical analysis:**

The data were subjected to analysis of variance (ANOVA), means were compared using least significant difference (LSD) at  $\leq 5\%$  probability level and calculated using MSTAT program according to Steel and Torrie (1982). The Langmuir and Freundlich parameters and the determination coefficient ( $R^2$ ) were calculated by Microsoft Excel 2010.

**RESULTS AND DISCUSSION**

**Phosphorus availability and soil pH**

The content of Olsen-P in clay soil after corn harvest significantly declined ( $P \leq 0.05$ ) with addition of organic acids at all treatments compared to the control (Table 2 and Figure 1). The lowest values of Olsen-P were noticed at organic acids treatments such as 0.5 % CA, 1 % CA and 0.5 % CA+TA. These treatments can be ranked considering Olsen-P reduction in the order of control > 0.2 % CA+TA > 1 % CA+TA > 1 % TA > 0.2 % TA > 0.5 % TA > 0.2 % CA > 1 % CA > 0.5 % CA > 0.5 % CA+TA. In current study, the comparison between additions of CA, TA and a mixture of CA+TA acids showed that the CA obtained the highest decrease values of Olsen-P. Moreover, at 0.5 %

concentration of all organic acids, the values of Olsen-P were the lowest. The phosphorus availability reduction might be attributed to the citrate ions present in soil solution that increase dissolving some minerals leading to the release of iron (Fe), Mg and Ca cations, which in turn interact with phosphorus (Jones and Darrah, 1994). Adding organic acids to the soil may lead to increase the solubility of calcium and phosphate compounds and this in turn formed insoluble calcium phosphate, which depends on the soil pH and free  $\text{Ca}^{2+}$  ions. However, the phosphorus availability in soil increased when pH is below 6 and decreased when pH is between 6 and 8 as a result of the additions of citrate (Oburger *et al.*, 2011) due to the deprotonation of  $\text{H}_2\text{PO}_4^-$  and  $\text{HPO}_4^{2-}$  at the higher pH values forming calcium–citrate–phosphate complex  $[\text{CaCitPO}_4]^{4-}$  (Rodgers *et al.*, 2006). The additions of citrate reduced the availability of phosphorus because of increasing  $\text{PO}_4$  adsorption through the adsorption of additional Ca that creates positive surface charges (Duputel *et al.*, 2013). Releasing phosphorus in soil solution is attributed to the amount and type of released organic acids as well as the physical, chemical and biological properties of the soil (Jones and Darrah, 1994). It is clear from these results that the presence of citric acid alone led to the reduction of Olsen-P compared to tartaric acid or citric and tartaric mixture due to several mechanisms may be (1) increasing solubility rates of calcium and phosphate ions, or (2) the formation of complexes between phosphate and calcium citrate ions. Consequently, the complex of calcium–citrate–phosphate in soil solution probably behave two fate (1) uptake by plants or (2) adsorb on surface clay minerals. After harvesting the soil pH was non significant which caused by the additions of organic acid (data not presented) due the high buffering capacity of this soil.

### Langmuir isotherm

The change occurred in the trends of (*b*) parameter with organic acids additions after corn harvesting (Table 2 and Figure 2). Significant increase of the (*b*) parameter in clay soil was happened with organic acids additions at all treatments compared to the respective control. The effectiveness of organic acids treatments in increasing the maximal adsorption capacity of phosphorus of this soil was in the order of 0.2 % TA > 0.5 % CA+TA > 0.2 % CA+TA > 1 % CA > 0.2 % CA > 1 % CA+TA > 1 % TA > 0.5 % CA > 1 % TA > control (Table 2 and Figure 2). The highest value of (*b*) parameter was obtained with the application of 0.2 % TA. The application of 0.2 % TA to this soil caused relative increases in the (*b*) parameter about 61.9 % compared to the control. The increased Ca concentrations in soil solution in presence of organic acids may increase the ionic strength of the solution which led to the electric surface potential to be less negative resulting in increased phosphate retention by the soil colloids (Oburger *et al.*, 2011). Increases of  $\text{PO}_4$  adsorption occurred due to adding citrate ions causing the adsorption of additional Ca that creates positive surface charges (Duputel *et al.*, 2013). The additions of citric acid at level of 1% and 0.2 % tartaric acid to clay soil led to a significant decrease in the energy of sorption or bonding energy (*k*) of phosphorus, while all treatments were lowered non significantly, except the addition of citric acid at level of 0.5% caused significant increases in the energy of sorption (Table 2 and Figure 3). These treatments can be ranked regarding the bonding energy (*k*) of phosphorus reduction of this soil in the order of 0.2 % TA > 1 % CA > 1 % TA > 0.2 % CA >

0.5 % TA > 0.5 % CA+TA > 1 % CA+TA > 0.2 % CA+TA > control > 0.5 % CA (Table 2 and figure 3). The MPBC parameter gives an index of the resistance to change in P concentration of the soil solution of the labile solid phase (Lair *et al.*, 2009). The values of MPBC can increase and decrease non significantly in the presence of organic acids (Table 2). The buffering capacity of phosphorus decreased in some soils treated with organic acids (Moradi *et al.*, 2012). In the soil under study, there was a presence of clay minerals commonly smectite which are saturated by calcium ions. These clay minerals will adsorb high amounts of phosphate. where calcium ions may create linkage between clay and phosphate ions leading to increase phosphate fixation in soils (Tisdale and Nelson, 1975; Tan, 2011). Formation of calcium–citrate–phosphate complex  $[\text{CaCitPO}_4]^{4-}$  arises as a result of deprotonation of  $\text{H}_2\text{PO}_4$  and  $\text{HPO}_4^{2-}$  at the higher pH. It causes a decrease in the quantity of free  $\text{Ca}^{2+}$  ions (Rodgers *et al.*, 2006).

**Table (2). Available phosphorus (Olsen-P), Langmuir and Freundlich parameters as affected by organic acids**

| Treatment | Olsen-P<br>mg kg <sup>-1</sup> | Langmuir parameters      |                         |                            | Freundlich parameters |            |                                      |                |
|-----------|--------------------------------|--------------------------|-------------------------|----------------------------|-----------------------|------------|--------------------------------------|----------------|
|           |                                | b<br>mg kg <sup>-1</sup> | k<br>L mg <sup>-1</sup> | MPBC<br>L kg <sup>-1</sup> | R <sup>2</sup>        | n          | K <sub>f</sub><br>L kg <sup>-1</sup> | R <sup>2</sup> |
| Control   | 11.9±0.31A                     | 772.3±59.6E              | 0.30±0.06AB             | 227.1±32.4ABC              | 0.9996                | 3.1±0.23C  | 215.1±2.0C                           | 0.9562         |
| 0.2 % CA  | 8.4±0.65D                      | 909.1±0.0CDE             | 0.24±0.01ABCD           | 216.3±11.6ABC              | 0.9999                | 2.7±0.02DE | 209.8±1.4CD                          | 0.9396         |
| 0.5 % CA  | 8.0±0.07D                      | 837.2±70.0CDE            | 0.33±0.06A              | 274.9±29.7A                | 0.9971                | 2.7±0.14DE | 219.1±1.7C                           | 0.8578         |
| 1 % CA    | 8.4±0.68D                      | 914.1±83.5CD             | 0.18±0.04CD             | 162.7±18.5C                | 0.9999                | 2.5±0.23EF | 180.4±10.9E                          | 0.9287         |
| 0.2 % TA  | 10.2±0.0BC                     | 1250.0±0.0A              | 0.14±0.00D              | 175.4±0.0C                 | 0.9904                | 2.2±0.02F  | 207.9±0.7CD                          | 0.9935         |
| 0.5 % TA  | 9.6±0.59C                      | 812.0±37.0DE             | 0.26±0.01ABC            | 211.8±13.4ABC              | 0.9986                | 2.9±0.08CD | 212.0±9.4CD                          | 0.9593         |
| 1 % TA    | 10.4±1.47BC                    | 909.1±0.0CDE             | 0.22±0.05BCD            | 199.3±44.0BC               | 0.9996                | 2.5±0.10E  | 199.8±14.7D                          | 0.936          |
| 0.2%CA+TA | 10.8±0.33B                     | 969.7±52.5BC             | 0.27±0.03ABC            | 260.1±24.0AB               | 0.9898                | 3.5±0.15A  | 298.2±8.1A                           | 0.9319         |
| 0.5%CA+TA | 8.0±0.35D                      | 1064.8±212.2B            | 0.26±0.16ABC            | 255.4±101.4AB              | 0.9865                | 3.4±0.29AB | 297.0±3.9A                           | 0.9434         |
| 1 %CA+TA  | 10.5±0.50BC                    | 909.1±0.0CDE             | 0.27±0.03ABC            | 243.5±24.48AB              | 0.9937                | 3.2±0.07BC | 260.4±8.8B                           | 0.9523         |

Values are mean ± standard deviation of triplicate measurements.

Values in the same column followed by the same letter do not differ significantly by LSD ( $p \leq 0.05$ ).

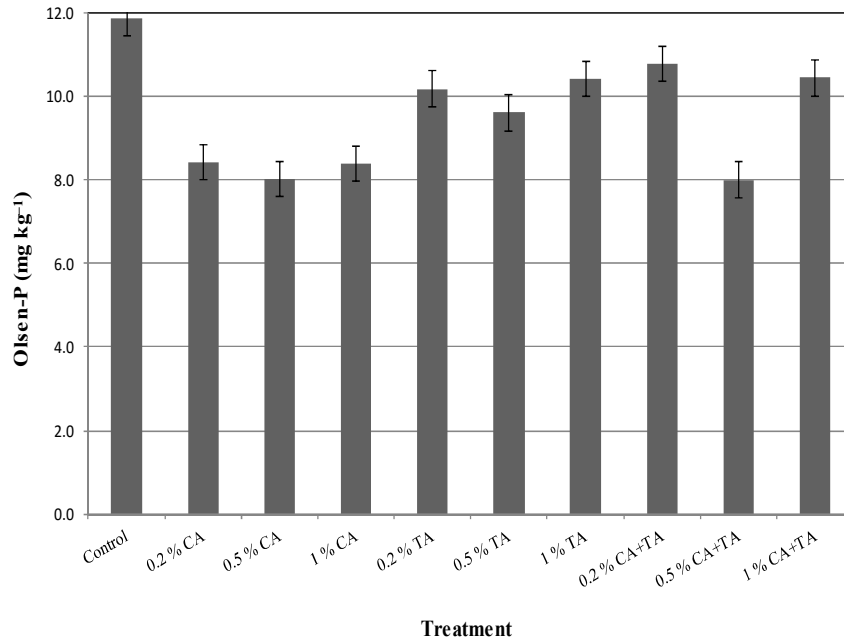


Figure (1). Changes of available phosphorus (Olsen-P) with adding organic acids in clay soil

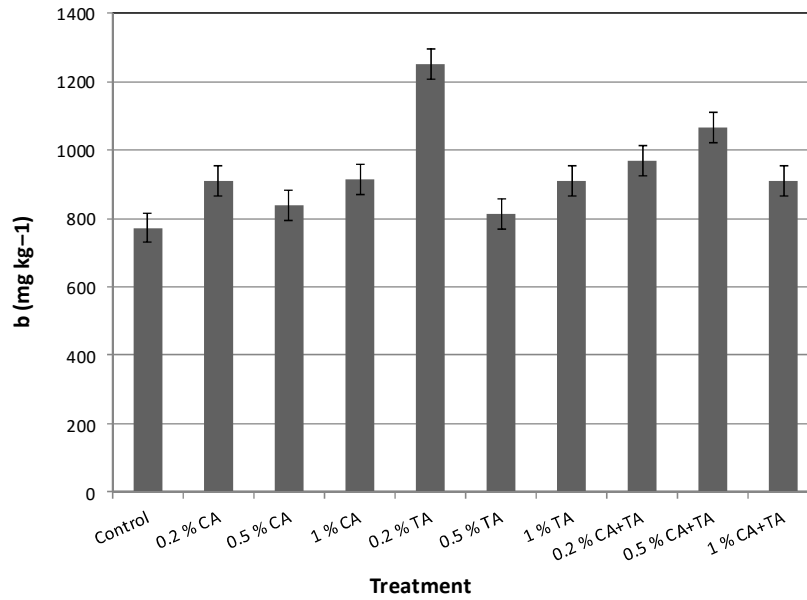
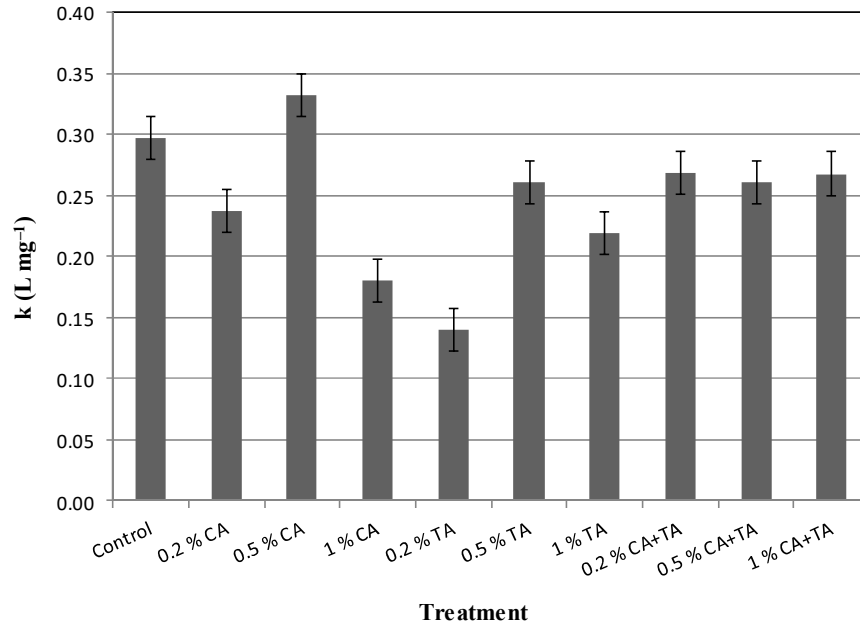


Figure (2). Effect of organic acids on trends of maximal adsorption capacity of phosphorus (b)

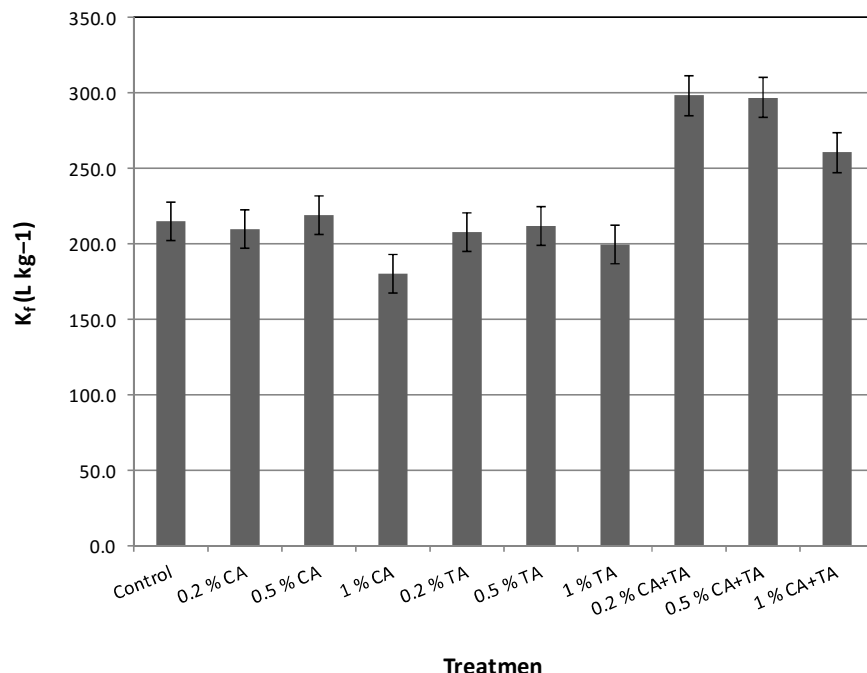




**Figure (3). Effect of organic acids on bonding energy ( $k$ ) of phosphorus**

#### Freundlich isotherm

Results showed that the effects of citric and tartaric acids in all treatments caused a significant decrease the sorption intensity constant ( $n$ ) compared to the control (Table 2). Treatments were ranked in the order of control > 0.5 % TA > 0.2 % CA > 0.5 % CA > 1 % TA > 1 % CA > 0.2 % TA concerning the reduction in sorption intensity constant. Similar results were also reported by (Moradi *et al.*, 2012) who found that the organic acids caused a significant decrease in the Freundlich  $n$  parameter of phosphorus. While, the additions of mixture of citric and tartaric acids increased  $n$  parameter significantly. The mixed citric and tartaric acids had increased the sorption intensity constant in the order of 0.2 % CA+TA > 0.5 % CA+TA > 1 % CA+TA > control. The results in this study showed that the effects of the mixed citric and tartaric acids at all treatments significantly increased the sorption capacity constant ( $K_f$ ) (Table 2 and Figure 4). The applications of 1% citric acid and 1% tartaric acid to clay soil caused significant decreases in  $K_f$  parameter. The organic acids also affected Freundlich  $K_f$  coefficient, hence they decreased it significantly (Moradi *et al.*, 2012). The phosphorus adsorption data were fitted satisfactorily by Langmuir and Freundlich equations, but slightly better by Langmuir equation than by Freundlich equation.



**Figure (4). Influence of organic acids on sorption capacity constant ( $K_f$ ) of phosphorus**

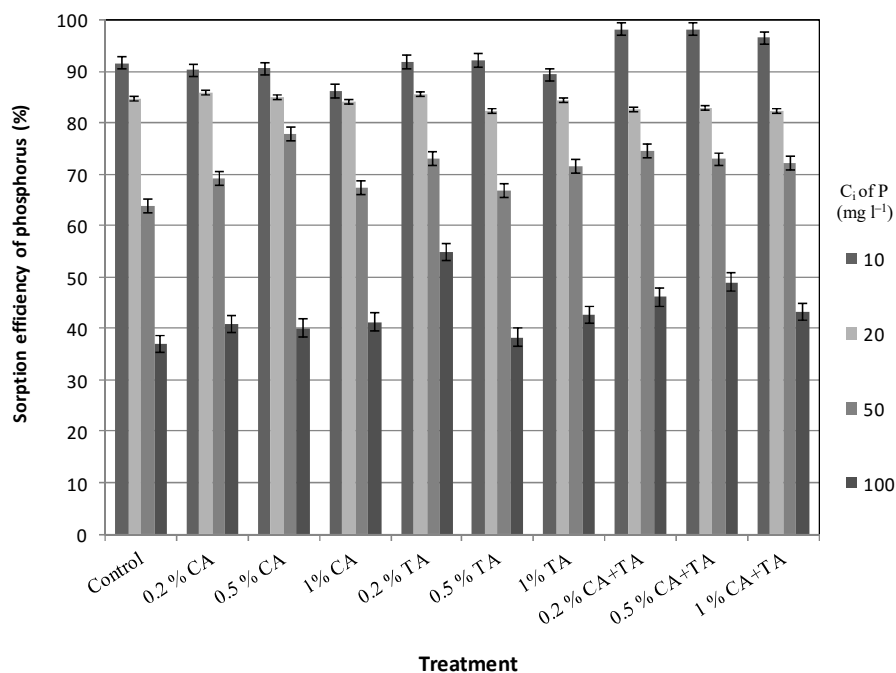
### Sorption efficiency of phosphorus

Predominately, the sorption efficiency of phosphorus tended to decrease at the high equilibrium concentrations. The results in this study related to the additions of organic acids on sorption efficiency of phosphorus after corn harvesting are shown in Table 3 and figure 5. The sorption efficiency of phosphorus at initial concentration of 10 mg kg<sup>-1</sup> increased at 0.2 % TA, 0.5 % TA, 0.2 % CA+TA, 0.5 % CA+TA and 1 % CA+TA treatments in comparison with control. But the application of some treatment such as 0.2 % CA, 0.5 % CA, 1 % CA and 1 % TA led to decreasing the sorption efficiency of phosphorus compared to the control (Table 3 and Figure 5). While, at initial concentration 100 mg kg<sup>-1</sup> the sorption efficiency of phosphorus increased at all treatments of organic acids compared to control. Treatments of organic acids used in this soil showed improvement in the phosphorus sorption efficiency at initial concentration of 100 mg kg<sup>-1</sup> in the order of 0.2 % TA > 0.5 % CA+TA > 0.2 % CA+TA > 1 % CA+TA > 1 % TA > 1 % CA > 0.2 % CA > 0.5 % CA > 0.5 % TA > control. Citrate adsorption can also increase PO<sub>4</sub> adsorption through electrostatic interactions with adsorbed Ca<sup>2+</sup> ions (Duputel *et al.*, 2013). The adsorption of phosphorus increased with high pH in presence of citric, oxalic and tartaric acids, but the different concentrations of citric, oxalic and tartaric acids did not affect P adsorption (Wang *et al.*, 2012).

**Table (3). Sorption efficiency of phosphorus as affected by organic acids**

| C <sub>i</sub> of P<br>(mg L <sup>-1</sup> ) | Organic acids treatment |             |             |           |             |             |           |                |                |              |
|--|-------------------------|-------------|-------------|-----------|-------------|-------------|-----------|----------------|----------------|--------------|
|  | Control                 | 0.2 %<br>CA | 0.5 %<br>CA | 1 %<br>CA | 0.2 %<br>TA | 0.5 %<br>TA | 1 %<br>TA | 0.2 %<br>CA+TA | 0.5 %<br>CA+TA | 1 %<br>CA+TA |
| <b>Q mg kg<sup>-1</sup></b>                  |                         |             |             |           |             |             |           |                |                |              |
| 10   | 183.2                   | 180.5       | 181.0       | 172.3     | 183.5       | 184.1       | 178.5     | 196.4          | 196.4          | 193.1        |
| 20   | 338.8                   | 343.8       | 340.0       | 336.7     | 342.2       | 328.9       | 337.6     | 330.3          | 331.2          | 329.1        |
| 50   | 638.4                   | 690.9       | 777.4       | 673.6     | 731.4       | 666.7       | 714.8     | 744.8          | 728.9          | 722.1        |
| 100  | 739.4                   | 817.3       | 802.0       | 825.4     | 1096.6      | 765.1       | 851.5     | 921.5          | 979.4          | 864.9        |
| <b>Sorption efficiency of phosphorus (%)</b> |                         |             |             |           |             |             |           |                |                |              |
| 10   | 91.6                    | 90.2        | 90.5        | 86.1      | 91.8        | 92.1        | 89.3      | 98.2           | 98.2           | 96.5         |
| 20   | 84.7                    | 85.9        | 85.0        | 84.2      | 85.6        | 82.2        | 84.4      | 82.6           | 82.8           | 82.3         |
| 50   | 63.8                    | 69.1        | 77.7        | 67.4      | 73.1        | 66.7        | 71.5      | 74.5           | 72.9           | 72.2         |
| 100  | 37.0                    | 40.9        | 40.1        | 41.3      | 54.8        | 38.3        | 42.6      | 46.1           | 49.0           | 43.3         |

\*C<sub>i</sub>: initial concentration



**Figure (5). Changes of phosphorus sorption efficiency as affected by organic acids**

### Fresh and dry Weight as well as phosphorus uptake of corn

The fresh weight of corn plants grown in the clay soil was significantly affected by additions of organic acids. The highest value of fresh weight was noticed at 0.5 % TA treatment (Table 4). The additions of tartaric acid at level of 0.5 % and citric+tartaric acids at level of 0.2 % caused significant increases of dry weight of corn plants. The amount of P uptake by corn plants was significantly increased with the additions of organic acids (Table 4). The highest P uptake value was at 0.5 % CA+TA treatment. The organic acids can cause a significant enhancement of phosphorus uptake by corn plants (Ström *et al.*, 2002).

**Table (4). Fresh weight, dry weight and P uptake as affected by organic acids**

| Treatment   | Fresh weight<br>g pot <sup>-1</sup> | Dry weight<br>g pot <sup>-1</sup> | P Uptake<br>mg pot <sup>-1</sup> |
|-------------|-------------------------------------|-----------------------------------|----------------------------------|
| Control     | 5.2±0.02E                           | 0.71±0.16CD                       | 0.93±0.03C                       |
| 0.2 % CA    | 6.6±0.14B                           | 0.84±0.07BC                       | 0.96±0.00C                       |
| 0.5 % CA    | 5.2±0.32DE                          | 0.72±0.07CD                       | 1.30±0.19B                       |
| 1 % CA      | 6.5±0.59B                           | 0.84±0.01BC                       | 1.64±0.04A                       |
| 0.2 % TA    | 6.1±0.45BC                          | 0.78±0.08BCD                      | 0.96±0.03C                       |
| 0.5 % TA    | 9.3±0.60A                           | 1.10±0.07A                        | 1.66±0.01A                       |
| 1 % TA      | 5.2±0.13E                           | 0.75±0.03CD                       | 1.78±0.11A                       |
| 0.2 % CA+TA | 6.5±0.04B                           | 0.90±0.04B                        | 1.31±0.15B                       |
| 0.5 % CA+TA | 5.8±0.00CD                          | 0.69±0.11D                        | 1.79±0.19A                       |
| 1 % CA+TA   | 5.8±0.44CD                          | 0.70±0.02D                        | 1.32±0.01B                       |

Values are mean ± standard deviation of triplicate measurements.

Values in the same column followed by the same letter do not differ significantly by LSD ( $p \leq 0.05$ ).

## CONCLUSIONS

The research goal of this study was to investigate the effect of type and concentration of two organic acids affecting on availability and sorption amount of phosphorus as well as corn growth and P uptake in the clay soil. The results of this study showed that the applying citric, tartaric and a mixture of citric and tartaric acids decreases Olsen-P after harvesting. The maximal adsorption capacity of phosphorus ( $b$ ) on caly soil increased with the additions of organic acids. Applying mixture of citric and tartaric acids led to a significant increase in ( $n$ ) parameter. The results in this study showed that the mixture of citric and tartaric acids at all treatments increased the sorption capacity constant ( $K_f$ ). The fresh weight and amount of P uptake for corn plants were increased with adding the tested organic acids. Therefore, applying organic acids affects the release and sorption of phosphorus dependeng on type and concentration of organic acids as well as soil properties.

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## الملخص العربي

# تأثير بعض الأحماض العضوية على تيسر وإدمصاص الفوسفور وكذلك نمو الذرة الشامية في تربة طينية

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الفرضيات التي تم اختبارها لهذه الدراسة هي تأثيرات بعض الأحماض العضوية على تيسر وإدمصاص الفوسفور في التربة الطينية وكذلك نمو الذرة الشامية و إمتصاص الفوسفور. في تجربة الأصص كانت الأحماض العضوية المستخدمة هي حامض الستريك وحامض الطرطريك وخليط منهما بنسبة ١:١ (وزن / وزن)، وقد أضيفت إلى التربة عند مستويات صفر ، ٠.٢ ، ٠.٥ ، و ١٪ (وزن / وزن). وضعت هذه التجربة في تصميم عشوائي تام مع ثلاثة مكررات و تم زراعتها بالذرة الشامية. النتائج التي تم الحصول عليها في هذه الدراسة أظهرت أن إضافة الأحماض العضوية إلى التربة أدى إلى انخفاض معنوي في كمية الفوسفور الميسر من ١١.٩ مجم/كجم لمعاملة الكنترول إلى ٨.٠ مجم/كجم عند مستوى ٠.٥٪ من الستريك وخليط من الستريك و الطرطريك. زادت السعة العظمى لإدمصاص الفوسفور (b) معنوياً مع إضافات الأحماض العضوية. إضافة خليط من أحماض الستريك و الطرطريك أدت إلى زيادة معنوية في ثابت شدة الإدمصاص (n). حدثت زيادة معنوية في ثابت سعة الإدمصاص (K<sub>f</sub>) مع خليط حامض الستريك و الطرطريك عند جميع التركيزات. ولكن إضافة ١ ٪ حامض ستريك و ١ ٪ حامض طرطريك إلى التربة الطينية أدت إلى إنخفاض معنوي في قيمة ثابت سعة إدمصاص الفوسفور. الوزن الطازج للذرة الشامية وكذلك إمتصاص الفوسفور تحسن معنوياً مع إضافة الأحماض العضوية.

**الكلمات الدلالية:** الفوسفور الميسر، الستريك ، الطرطريك ، شدة الإدمصاص، ادمصاص الفوسفور

