# Phosphorus adsorption characteristics and release risk in saline soils: a case study of Songnen Plain, China

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## Contents

## Abbreviated list

Lightly saline soil : LS
Moderately saline soil : MS
Heavily saline soil : HS

Electric conductivity : EC
Soil organic matter : SOM
Cation exchange capacity : CEC
Total N : TN
Total P : TP

Phosphate sorption index : PSI
Degree of P saturation : DPS
Eutrophication risk index : ERI

Method for fractional determination of phosphorus:

The study used the Hedley classification method to classified the adsorbate for phosphorus, and determined $Ca_2$-P, Al-P, Org-P, Fe-P, O-Al-P, O- Fe-P, $Ca_{10}$-P.

(1) $Ca_2$-P: put 0.5 g of sample through 100 mesh sieve into a 50 mL centrifuge tube, add 25 mL of 0.25 mol/L NaHCO3 (pH 7.5), shake for 1 h, centrifuge, and wash the residue with 25 mL of ethanol;
(2) Al-P: Add 25 mL of 0.5 mol/L $NH_4F$ (pH 8.5) to the residue in (1), shake for 1 hour, centrifuge, and wash the residue with 25 mL of saturated NaCl;
(3) Org-P: (2) Add 0.7 mol/L NaClO (pH8.05) to the residue in 25 mL boiling water bath for 30 minutes, cool and centrifuge, and wash the residue with 25 mL saturated NaCl;
(4) Fe-P: Take residue from (3) and add 25 mL of 0.1 mol/L NaOH-0.1 mol/L $Na_2CO_3$, shake for 2 h, then let stand for 16 h, shake for 2 h, centrifuge, and use 25 mL of saturated NaCl for the residue Wash 2 times;
(5) O-Al-P: Take residue from (4) and add 25 mL of 1 mol/L NaOH to a water bath at 85 ℃ for 1 h. After cooling, centrifuge, and wash the residue twice with 25 mL of saturated NaCl;
(6) O-Fe-P: Take residue from (5) and add 20 mL of 0.3 mol/L sodium citrate, stir evenly, add 0.5 g $Na_2S_2O_4$, 80 ℃ water bath, add 1 mol/L NaOH 5 mL, centrifuge, then wash residue twice with 25 mL saturated NaCl and retained.
(7) Ca10-P: Add 25 mL of 0.25 mol/L $H_2SO_4$ to the residue in (6), shake for 1 hour, and centrifuge.

The above experiments were set up with 3 groups of replications.

The fundamental physicochemical characteristics of the examined soil were assessed using the approach outlined in the publication 'Routine Analytical Methods of Soil Agrochemistry' (Bao et al., 1988), and the findings were presented in Table 1 and Table 2.

The above experiments were set up with 3 groups of replications.

Table S1 Supplementary Equation

| | Equation |
|---|---|
| Phosphorus adsorption expression | $q_t = (C_0 - C_t)V/m$ (Eq.1) |
| Kinetic equation for phosphorus adsorption | Pseudo-first-order model ：$q_t = Q_{e,1}(1 - e^{-k_1 t})$ (Eq.2) |
| | Pseudo-second-order model：$q_t = \frac{Q_{e,2}^2 k_2 t}{1+Q_{e,2}k_2 t}$ (Eq.3) |
| Isothermal equation for phosphorus adsorption | Langmuir equation：$q_e = \frac{K_L q_m C_t}{1+K_L C_t}$ (Eq.4) |
| | Freundlich equation：$q_e = K_F C_t^{1/n}$ (Eq.5) |
| Thermodynamic parametric equations: | $K_F = \frac{(C_0-C_e)V}{C_e m}$ (Eq.6) |
| | $\ln K_F = \frac{\Delta S}{R} - \frac{\Delta H}{RT}$ (Eq.7) |
| | $\Delta G = \Delta H - T\Delta S$ (Eq.8) |

**Phosphorus adsorption expression**

Where: $q_t$ is the amount of phosphorus adsorbed at time t (mg/kg); $C_0$ and $C_t$ are the mass concentration of phosphorus in the adsorption system at the initial and t moments, respectively (mg/L); V is the volume (mL); m is the weight of the sample (g).

**Kinetic equation for phosphorus adsorption**

Where: $q_t$ is the amount of phosphorus adsorbed at equilibrium (mg/g); $q_e$ is the amount adsorbed at time t (mg/g); $k_1$ is the rate constant for The pseudo-first-order model (h); $k_2$ is the rate constant for pseudo-second-order model adsorption [g/(mg-h)].

The Pseudo-first-order model can be used as an explanation of the initial phase of adsorption, while the Pseudo-second-order model is applicable to the entire adsorption phase of this experiment.

**Isothermal equation for phosphorus adsorption**

Where: $q_e$ is the mass concentration of phosphorus in the solution system at equilibrium (mol/L); $K_f$ is the Freundlich equilibrium constant; n is a constant characterizing the strength of adsorption; $q_m$ is the theoretical maximum adsorption amount (mg/kg); and $K_L$ is the adsorption affinity coefficient (L/mol).

**Thermodynamic parametric equations:**

Where: ΔG is the Gibbs free energy change (kJ/mol); K is the thermodynamic equilibrium constant, which can be fitted by the Langmuir equation (L/mol); R is the ideal gas constant, 8.314 [J/(mol-K)]; T is the reaction temperature (K); ΔH is the standard enthalpy change (kJ/mol); ΔS is the standard entropy change [kJ/(mol-K)]; the relationship between ΔG ～T, the slope and intercept of the line correspond to the values of ΔS and ΔH, respectively.

Table S2: Comparison of phosphorus adsorption characteristics of different adsorbents

| Adsorbents | pH | SOM (g/kg) | Equilibrium concentration (mg/L) | Time (min) | $q_m$ (mg/kg) | Temperature (℃) | References |
|---|---|---|---|---|---|---|---|
| Black calcium soil | 8.23 | 8.60 | 0~150 | 0~1440 | 2057 | 298K | (Zhao et al., 2022) |
| Alfisol | 6.51 | 17.28 | 20~300 | 0~2880 | 1248 | - | (Jing et al., 2024) |
| Black soil | 6.93 | 27.25 | 30~100 | 0~1440 | 1432 | 298K | (Xue et al., 2023) |
| surface soil layer from the farmers'fields India | 7.53 | 0.59 | 0~80 | 0~2880 | 80 | - | (Sharma et al., 2023) |
| Surface farm soil | 6.74 | 23.90 | 5~45 | 0~1440 | 207 | 298K | (Amarh et al., 2021) |
| Red soil | 6.30 | - | 0~150 | 482 | 570 | 296K | (Ilori et al., 2023) |

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