



## The Degree of Saturation with phosphorus (PSI, Phosphorus Saturation Index) in soils of the Central Region of Córdoba (Argentina)

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**Abstract**— The objective of this work was to estimate the degree of saturation of P (PSI, phosphorus saturation index) of the soil from its maximum adsorption capacity and confirm its suitability as a predictor of potential loss of P. The maximum adsorption capacity of P (Q<sub>max</sub>) obtained from of the Langmuir adsorption isotherm and the degree of saturation of soil P (PSI) using Q<sub>max</sub> and extractable P (P-Bray). The PSI obtained were in a range between 12 to 39%. The high PSI values observed at a depth of 0 to 5 cm suggest that these soils are vulnerable to P loss and determine the need to evaluate the potential for soluble P losses in runoff and drainage waters.

**Keywords**— retention, adsorption, pollution, transport, desorption.

### I. INTRODUCTION

Fertilizers and organic amendments containing phosphorus (P) are applied to soils with the main objective of increase the bioavailable supply of orthophosphate to the roots of plants. However, when added to soil, orthophosphate is immobilized in chemical forms that are not immediately available to plants [14, 24].

In conditions of continuous agriculture, to counteract negative nutritional balances, crops require P applications on a regular basis, which leads to the accumulation phosphate compounds in the soil in chemical forms of low bioavailability. This low availability of P is associated with the high stability and low solubilization and mineralization rate of the phosphate compounds [5].

The need to apply more P than was extracted in the harvested crop raises the need to know the fate of residual phosphate [11].

The ability of soils to retain P is an important parameter to determine the fate of this element both from the point of view of plant nutrition as well as from the point of view of contamination of the environment [19].

Among all the phenomena that govern the mobility of substances in porous media, the transfer of ions from a liquid phase to a solid phase is a universal phenomenon. That is the reason why the "isotherm", a curve that describes the retention of a substance in a solid at various concentrations, is an important tool to describe and predict the adsorption of compounds such as phosphate fertilizers [2].

There is a wide variety of equilibrium models, isotherms, that allow the study of sorption-desorption processes [13]. The advantage of using the Langmuir isotherm in P sorption studies is that it allows estimating the maximum adsorption capacity of P (Q<sub>max</sub>). However, it is considered operationally complex to be used as routine analysis, so the concept of saturation degree of P has recently been introduced as an environmental index of soil, indicator of P available to be released through runoff and leaching to groundwater and surface water reservoirs [1,18]

By combining the Q<sub>max</sub> value of the Langmuir isotherm with the available P values, a characterization of the degree of soil P saturation (PSI) can be obtained, which helps to predict the potential of the soil to release P [17]

In Argentina, for the production areas of the extra pampean region, there are no studies that make a characterization of the PSI in a soil under continuous tillage, especially in the production areas of the central region of the country, converted into pure agricultural systems that were initially livestock systems.

The objective of this work was to determine the PSI from the adsorption parameters of Langmuir, and to confirm its Aptitude as a predictor of the potential release of the adsorbed P in soils under direct seeding and continuous agricultural conditions.

## II. MATERIALS AND METHODS

Experimental studies were carried out for assessment of sorption P. The research was carried out in the Soils Transfer Centre 3.0 of the Faculty of Agricultural Sciences at the National University of Córdoba (Argentina). We worked with soil samples from production plots under continuous agriculture under direct sowing (DS) conditions in the central region of the province of Córdoba (Argentina).

The soils studied were Haplustolls (Entic H. and Typic H.) that are characterized as highly productive soils. The high content of silt (> 40%) gives them a certain fragility and structural instability [22].

The region was deeply modified by the expansion of the agricultural frontier with an important substitution of natural vegetation (Espinal) for summer crops [26] and marked edaphic changes as a result of continuous direct sowing.

In each batch studied, composite samples (by 30 sub-samples) were taken from the upper 5 cm of the profile, air dried and sieved through a 2 mm mesh. It was determined: A) P extractable Bray [4], B) soil organic matter content (SOM) by the Walkley & Black method [16], and C) the maximum adsorption capacity ( $Q_{max}$ ) following the methodology for the adsorption tests proposed by [21]. The phosphorus adsorption capacity was determined by means of adsorption isotherms. The value of adsorbed P was obtained as the difference between remnant and initial solution P content.

The results were modeled using the Langmuir equation:

$$Q = \frac{Q_{max} \times k \times C}{1 + (k \times C)}$$

where the variable  $C$  ( $\mu\text{g P ml}^{-1}$ ) is the concentration of P in solution in equilibrium with the P adsorbed ( $Q$ ),  $Q_{max}$  ( $\text{mg P kg}^{-1}$ ) is the maximum adsorption and  $k$  is a constant related to the binding energy of the P particles.

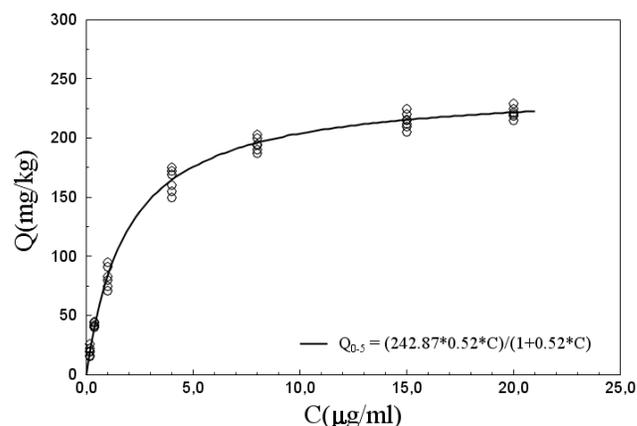
The PSI defined by [17] was calculated using the  $Q_{max}$  values obtained from the Langmuir isotherms of each batch experiment:

$$PSI_{Langmuir} = [P-Bray] \times [Q_{max} + P-Bray]^{-1} \times 100$$

The results were analysed by fitting the isotherm data to non-linear regression models; analysis of variance was used to identify differences among means of Langmuir parameters (LSD Fisher at  $p < 0.05$ ). These analyses were conducted with InfoStat software [7].

## III. RESULT AND DISCUSSION

Figure 1 shows the experimental adsorption values corresponding to one of the soil samples evaluated. The experimental data were obtained for a range of solution P added between 0 to 20  $\text{mg P L}^{-1}$  and adjusted to the Langmuir model.



**Figure 1: Relationship between the adsorbed phosphorus ( $Q$ ) and the P concentration in the equilibrium soil solution ( $C$ ) for the depth of 0-5 cm; the parameters of the Langmuir model are reported in the figure legend.**

As can be seen in Figure 1, the concentration of P in equilibrium varied between 0.25 and 20  $\text{mg P L}^{-1}$ . This behavior was observed in all the soil samples evaluated.

In samples with SOM contents greater than 40  $\text{g kg}^{-1}$  (Table I), desorption of P from the solid phase of the soil to the soil solution occurred for the range of concentrations between 0 and 3  $\text{mg L}^{-1}$  P added. This is because native P adsorbed in soils with high SOM contents is less strongly retained and therefore is more easily released to the soil solution [12, 21].

**Table I**  
**Contents of P-Bray, soil organic matter (SOM), maximum adsorption coefficient of the Langmuir equation ( $Q_{max}$ ), P saturation index ( $PSI_{Langmuir}$ ) calculated from P-Bray and  $Q_{max}$  for the 0 to 5 cm layer from each of the evaluated sites.**

Site	SOM	P-Bray	$Q_{max}$	$PSI_{Langmuir}$
	$g\ kg^{-1}$	$mg\ kg^{-1}$		%
1	20.2	31.5	222.88	12
2	20.0	34.3	187.35	15
3	23.1	33.4	271.98	16
4	23.9	27.2	216.55	18
5	35.6	73.1	241.31	23
6	61.8	80.5	253.74	24
7	64.1	108.0	275.72	28
8	64.2	113.8	279.47	29
9	60.3	106.6	242.87	31
10	79.3	153.5	237.66	39

Recent studies [8, 9] showed the existence of a positive correlation between microbial respiration and changes in extractable P measured in laboratory incubations. They suggest that this is because the solubilizing microorganisms of the P have greater access to the different fractions of inorganic P when they are in the presence of C-rich substrates; they attributed this pattern to the participation of the microbial fraction in the desorption phenomena.

Fernández López and Mendoza (2013) argue in relation to the effect of SOM and desorption, that the forms of labile organic P are mineralized under incubation conditions, and that the non-labile forms of organic P do not change over time with the aggregate P. This suggests that under cultivation conditions forms of organic recalcitrant P are stabilized in the soil, and may have little influence in the short or medium term in the desorption of P.

The maximum adsorption capacity ( $Q_{max}$ ) and the retention affinity constant ( $k$ ) were estimated using non-linear regression models from the relationship between the adsorbed amount P and the equilibrium P concentration [7].

The  $Q_{max}$  values ranged between 187 and 279  $mg\ kg^{-1}$  (Table I). There were no significant differences in  $Q_{max}$  values between samples.

The retention energy ( $k$ ) of the Langmuir isotherm showed significantly lower values in the samples with  $SOM > 40\ g\ kg^{-1}$  with a tendency to increase the maximum

adsorption and decrease the affinity, which indicates that there will be a greater availability of P in the solution. According to the interpretation of [23], this behavior characterizes the sorption of phosphate fertilizers applied in organic carbon rich soils. The authors explain that the first population of P retention sites is satisfied by the organic P, so the phosphate adsorption process contributed by the fertilizers covers the second population of sites (less active). These require less energy for desorption, which from the environmental point of view increases the potential risk of contamination.

From the  $Q_{max}$  of the Langmuir isotherm and the P-Bray values, the Langmuir PSI values were calculated [17], which are presented in Table I.

The values obtained varied between a minimum of 12% and a maximum of 39%, with an average value of 23.5%. PSI values greater than or equal to 20% have been reported in the literature as the limit for protecting the surface of water reservoirs from P contamination [6, 20, 23].

Langmuir PSI values less than 20% were found in soil samples with P-Bray contents less than 35  $g\ kg^{-1}$ . In this way, due to the inverse and exponential relationship between the initial P and the absorbed P, it is expected that the added P will quickly occupy the adsorption sites in the sites with the lowest P-Bray content.

There is a critical need for a practical index to assess the phosphorus movement potential of a given site to surface waters, either through surface runoff or subsurface drainage. That index is the degree of phosphorus saturation (PSI, Phosphorus Saturation Index), which relates the measure of the P already adsorbed by a soil with its adsorption capacity. Nair et al. (2004). suggest that PSI values can be used as predictors of soil P loss, regardless of soil depth within a given profile.

The high values of  $PSI_{Langmuir}$  indicate that in the studied soils the P balance should be negative to reduce the risk of P loss and the possible eutrophication of surface waters [3].

#### IV. CONCLUSION

The PSI integrates all the effects of soil properties that regulate the sorption phenomena with the P content in the soil analysis and acts as a potential estimator of the loss of soil P. The high values of PSI observed at a depth of 0 to 5 cm indicate that the Haplustolls soils of the central area of the Province of Córdoba, Argentina, are vulnerable to the loss of P and this suggest the need to evaluate its potential for the release of soluble P in the runoff and drainage waters.



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