



Texture Influence on Soil Phosphorus Content and Distribution in Semiarid Pampean Grasslands

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Authors' contributions

This work was carried out in collaboration between both authors. Author JAG designed the study, author LS carried out laboratory work, managed the literature searches and wrote the first draft of the manuscript. Authors LS and JAG managed statistical analysis and wrote discussion and conclusion. Both authors read and approved the final manuscript.

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ABSTRACT

Soil texture can modify the content and dynamic of soil phosphorus (P). The objective of this work was to study the P form contents associated to physical fractionation of SOM in soils with different texture. Soil samples (0-0.15 m) were obtained from 27 sites with different texture in a twenty five years old pasture located in the Experimental Station of Bordenave, Argentina (63°01'20"W; 37°51'55"S). Soil particle size fractions were obtained by wet sieving separating the fine (0-100 µm) and coarse (100-2000 µm) fractions. Soil organic matter was determined in each fraction, mineral associated (MOM) and particulate organic matter (POM), respectively. Extractable (Pe), organic (Po), inorganic (Pi) and total extractable (Pt) phosphorus was determined and occluded P (PoCl) was calculated as the difference [Pt - (Po+Pi)] in the whole soil and the particles fractions. In these soils, texture determines P reserves and the equilibrium of its different forms. Available P forms (estimated by Pe) was related to the inorganic form present the fine fraction of the soil. Phosphorus content in its different forms is closely associated with soil fractions. Soils with higher content of fine fraction present the coarse fraction enriched in Po. All the studied P forms were

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higher in fine textured soils than in coarse ones, however, P forms in particle size fractions showed different tendencies. In coarse textured soils, Po in MOM was lower than fine textured ones. However, P content in MOM was richer and in POM was poorer than in fine textured soils. The available P, estimated with Pe content, comes predominantly from the inorganic pool and it is associated to the fine fraction of the soil. Phosphorus content in its different forms is closely associated with soil size fractions. It was proposed a conceptual model in which size fractionation of SOM and P forms determination can be represented to a better understanding of soil P equilibriums.

Keywords: Particle size fractionation; phosphorus fractions; organic matter; phosphorus dynamics.

1. INTRODUCTION

Soil texture influences the soil microenvironment and soil organic matter (SOM) mineralization in several ways. It has been reported that the higher clay content, the content of organic matter is enhanced [1]. Soil texture affects N and P availability by influencing SOM accumulation [2,3], soil microbial activity [4] and physicochemical equilibriums [5]. However, different pools of SOM are differently affected by soil texture [6,7]. Since soil texture affects SOM storages through direct and indirect mechanisms, total SOM may not be an universal predictor of soil quality [8]. The precise nature of the impact of soil texture on phosphorus (P) equilibrium and dynamics and on P availability is still unknown [9-11]. Soil texture can modify P equilibrium and availability as a consequence of its mineral physicochemical properties, its influence on phosphate adsorption – desorption - diffusion processes, and through SOM mineralization-immobilization by microbial activity [2,4].

The quantity and lability of inorganic P (Pi) depends on the distribution of different soil particle sizes, their parental material and weathering degree. Though P is much less mobile than other nutrients in the soil, like nitrates or sulphates, the direct impact of soil texture on P availability is highly relevant to crop production [12]. In sandy soils, phosphate diffusion towards crop roots is lower [13]; in loamy soils, fixation can be higher, thus decreasing the pool of available P. Different soil textures therefore generate a wide range of behaviour of P in soil [14,15].

The effect of soil texture on the stabilization of organic matter fractions in soils from the semi-arid Pampean region has been studied by several authors [16,17,6]. There is information about P form dynamics [9] and on P availability to crops [18] but less about the influence of the particle size soil over this dynamics [19].

Complex chemical fractionation procedures have been developed [20,21] to evaluate the quantity, availability and dynamics of the main P forms in soil. Applied to different pools of P corresponding to forms with different physicochemical properties, these procedures throw light on differences in the chemical resistance and biological susceptibility to degradation, giving rise to extremely detailed descriptive models which in some cases exceed field validation possibilities [22]. However, more recently, physical fractionation methods based on SOM particle size have here been developed to separate organic fractions with very different characteristics and dynamics [23-25,6]. It is therefore now possible to distinguish between SOM associated to fine or coarse fractions, which shown their different structure and function. The fine soil fraction (clay, silt) corresponds to a more humidified or mineral-associated organic matter (MOM), and the coarse fraction (different sizes of sand) to less transformed, labile, young [26,23] or light [27] or particulate organic matter (organic crop residues in different transformation stages) (POM) [25,28]. The MOM is primarily responsible for the union with minerals in the soil, generating the organo-mineral complexes basic to the formation of micro-aggregates that determine soil structure. The POM on the other hand is the more dynamic component, playing an active role in nutrient flows and therefore closely associated with the availability of nutrients to crops [29-32].

Since both fractions are relevant to soil fertility, it is important to establish their organic (Po) and inorganic (Pi) phosphorus content and to relate these with soil texture. It could be expected differences between P content in both particle size fraction: in the fine fraction is likely to be the more stable Po (Po-MOM) and the more available Pi (Pi-clay and silt sizes); in the coarse fraction is likely to be labile or no labile Po (Po-POM) and less available Pi (Pi-sand size) in the short term. P in the fine fraction is likely to be the

more stable Po and the more available Pi; in the coarse fraction Po is likely to be labile or moderately labile, with the presence of Pi in the bigger minerals, presumably with less possibility of transforming into phosphates in the short term.

The hypothesis of the current paper is that soil texture modifies the equilibriums of the different P forms in the soils of the semi-arid Pampean region, mainly through stabilization in the resistant organic forms in fine textured soils and accumulation in the labile organic forms in sandy soils. The aim of the study is to determine the content and distribution of the main P forms in soils textural different and to relate with the available P index. The second aim is propose a conceptual to identify P changes due to textural soil characteristics.

2. MATERIALS AND METHODS

2.1 Experimental Site

The sampling sites are located in Bordenave, Argentina (63°01'20"W; 37°51'55"S), and are representative of the central-southern semiarid Pampean region. The climate is temperate continental semiarid (Csb) [33]. The average annual temperature and rainfall are 15.2°C and 667 mm (1928-2005), respectively.

The dominant soils in this region are Entic Haplustolls and Entisols (Soil Taxonomy) having a mixed, loamy to sandy texture, with an horizon sequence A-AC-C-Cca, and featuring a caliche layer at an average depth of 0.6 to 1.5 m [34]. At the sampling time native grass species (*Stipa* spp, *Bromus* spp, and *Medicago polymorfa* L.) were the dominant vegetation in these soils, which were previously covered by mixed pasture (*Medicago sativa* L., *Phalaris* sp L., and *Festuca arundinacea* Schreb.) for more than two decades.

A relatively small field area (about 12 ha) that is characterized by a natural micro-heterogeneity of texture was considered in this study. This choice was made in order to assess the influence of texture on SOM and nutrient distribution in soil particle-size fractions avoiding other effects due to mineralogy, pH, climatic conditions, microbial populations and recent management regimes [35].

In December 1992, surface soil composited samples (A horizon, 0-15 cm depth) were collected randomly from 27 sites featuring a

different texture in the study area (Table 1).

Carbon (SOC) by dry combustion (LECO Carbon analyzer), and the following P forms were determinate:

- Extractable (Pe) by Bray-Kurtz 1 [36]: extraction with hydrochloric acid (HCl) 0.025 M and ammonium fluoride (NH₄F) 0.03 M (pH 2.9), soil/solution ratio 1:7, shaking time 1 min, this method is indicated for soils with neutral to slightly acid pH [37]. Pe was not determined in the fractions because of physical separation of particles could wash some available P forms.
- Total extractable (Pte) [38], with a perchoric acid digestion to 270°C;
- Total (Pt) with sodium carbonate [39], 0.1-1 g sample is fused in sodium carbonate (Na₂CO₃) to 900°C followed by disintegration of the melt in chloridric acid (HCl)
- Organic (Po) and inorganic (Pi) by Saunders and Williams [40] method extraction with sulphuric acid (H₂SO₄) 1N, shaking time 16 hours; Po is determined by difference between a calcined soil sample (in muffle to 550°C) and another one without calcine.
- The occluded P (Pocl) was calculated as the difference between Pt - (Po+Pi). Some authors consider that Pocl is strongly adsorbed or precipitated and it has very slow plant availability [41]. In this work, we consider that the Pocl is the P chemically unextracted by the Saunders and Williams [40] method.

Inorganic P in all extracts was determined by the ammonium vanadate colorimetric method [42]. All these methods are fully described by Sparks et al [43]. Soil pH was determinate with a glass electrode at a 1: 2.5 water ratio [44],

2.2 Soil Physical Determinations

For the size fractionation of soil, we used the wet sieving of soil [25,6]. Briefly, 50 g of soil previously air-dried and sieved (2 mm) were dispersed in glass containers of 120 mL, and mixed with 100 mL of distilled water. Ten glass beads (5 mm diameter) were added to increase aggregate destruction and reduce potential problems created by different content of sand [25]. The samples were subjected to mechanical dispersion through a rotary shaker for

approximately 16 h (overnight at 40 rpm) to disintegrate the aggregates. The sieving was done with a sieve of 140 mesh, making moves back and forth until the water coming out through the sieve was clear to the naked eye. Two particle size fractions were obtained: the fine fraction (0-100 μm) and the coarse (100-2000 μm) both fractions were oven dried at 65°C. The fine fraction contained clay, silt, very fine sands and humified or mineral associated organic matter (MOM). The coarse fraction had sand and organic matter less transformed also called young or particulate organic matter (POM). The same chemical methods above were also applied to determinate Pte, Po and Pi in both fractions.

2.3 Statistical Analysis

Statistical analysis was performed using analysis of the variance (ANOVA) and least significant differences (LSD), regression analysis, and main components procedures with InfoStat software [45].

3. RESULTS AND DISCUSSION

3.1 Phosphorus in the Soil

There was a positive correlation between total P and P forms contents and silt and clay content of the soil (Fig. 1). The total P reserve (Pt) ranging from 300 to 600 $\mu\text{g g}^{-1}$, depending on soil silt and clay contents ($R^2= 0.70$, $p<0.001$). Greater sand content triggers dilution of the P content, thus decreasing the total P reserve in sandy soils. A similar behavior was observed for the rest of the P forms studied. However, when the most available forms were analyzed, the decreasing correlations following the order Pi ($R^2= 0.65$, $p<0.01$) > Po ($R^2= 0.61$, $p<0.05$) > Pe ($R^2= 0.50$, $p< 0.05$) show that other factors are also at work in modifying the equilibriums. Taking into account the fact that climate and vegetation conditions were similar, it is inferred that soil texture accounts for over 50% of the variability of the soil P forms.

Table 1. Extractable phosphorous (Pe), texture y pH of studied soils

Soil number	Pe $\mu\text{g g}^{-1}$	clay+silt %	sand	pH
1	16.4	14.5	85.1	6.5
2	16.1	14.1	85.8	6.6
3	14.1	31.7	68.3	6.8
4	38.9	65.6	24.4	6.8
5	10.8	26.6	73.4	6.8
6	23.1	38.0	62.0	6.8
7	34.4	38.2	61.8	7.7
8	22.6	39.5	60.5	7.1
9	30.8	57.3	42.7	7.2
10	16.8	14.8	85.2	6.8
11	25.0	14.3	85.7	6.7
12	19.4	29.2	70.8	6.9
13	53.9	59.9	40.1	6.8
14	12.3	29.4	70.6	6.8
15	35.2	35.2	64.8	6.6
16	20.9	36.8	63.2	7.6
17	21.5	45.7	54.3	7.0
18	30.1	55.5	44.5	7.2
19	18.7	13.9	86.1	6.7
20	12.3	14.9	85.1	6.7
21	22.8	31.7	68.3	6.8
22	62.9	62.6	37.4	6.6
23	12.7	27.3	72.7	6.7
24	34.4	34.3	65.7	6.7
25	36.5	37.1	62.9	7.1
26	15.5	45.2	54.8	7.0
27	30.4	54.0	46.0	7.2
LSD	13	15	20	0.2

3.2 Phosphorus in the Soil Fine Fraction

In the fine fraction, there were a positive correlation phosphorus forms and clay and silt contents of soil (Fig. 2). Pt and Pi had the most marked slopes and the highest coefficients, whereas Po showed greater variability. The difference between Pt and (Po+Pi), or occluded P, was greater in the finer textured soils, suggesting that these soils finer particle size provides greater protection.

This shows the importance of the smaller mineral fraction for P equilibrium and could also indicate a higher level of precipitation [46], fixation and other physico-chemical processes. Furthermore, the different slopes in the equations obtained for Pi and Po could indicate that the relationship between the different P forms varies with differences in soil texture. Thus the Po: Pi ratio was lower for sandy soils than for fine textured soils, as observed in the organic fractions [6]. In predominantly sandy soils Po contributed significantly to the total whereas in finer textures the Pi reserve was the highest. The implication for actual and potential fertility is that sandy soils are more highly dependent on SOM mineralization cycles and that the excessive loss of SOM could have a high impact on sustainability. If biological mineralization of organic P is the main mechanism, natural P equilibrium in fine textured soils can be restored through the supply of inorganic fertilizers but in sandy soils through the supply of organic residues. A close correlation between the fine fraction and the associated organic matter was observed, but not so in the case of Po content.

As corroborated by determined P values without take into account fine fraction content of P (data not shown), these results indicated that MOM (associated with fine matter <0.1 mm) contains less P when the soil texture was finer. Another study carried out on the same soils showed that the sandier the soil, despite its lower SOM content, it was richer in nitrogen and sulphur content [6]. It is meant, although MOM content is lower in sandy soils, it may be richer in N, S and P. The amount of these nutrients released during mineralization could be proportionally higher, thus making up for the lower amount of SOM.

3.3 Phosphorus in the Soil Coarse Fraction

Differences in the relationship between the various P forms and texture were observed in the coarse fraction. Pt was lower in finer textured soils, Po was higher and Pi showed no definite trend or great variability (Fig. 3). The higher amount of coarse particles (>0.1 mm) in sandy soils corresponded mainly to minerals with a non-significant P contribution to this fraction. On the other hand, a significant correlation between particulate organic matter (POM) and texture was observed in previous studies, accounting for the higher Po in soils with more fine fractions [6].

These results showed the shift in relative importance of each of these fractions in soils with different texture. Pi content in the coarse fraction was highly variable and showed no definite trend, varying around 150 mg kg⁻¹, whereas Po content increased with increasing amounts of fine matter [10]. Since more fine fractions means less coarse

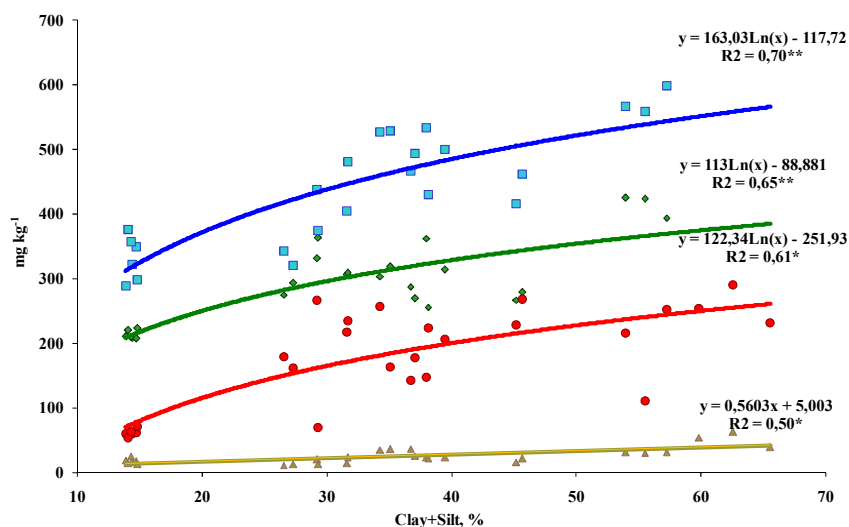


Fig. 1. Extractable (Pe, yellow) organic (Po, red), inorganic (Pi, green) and total (Pt, blue) phosphorous contents versus percentage of clay and silt (n=27)

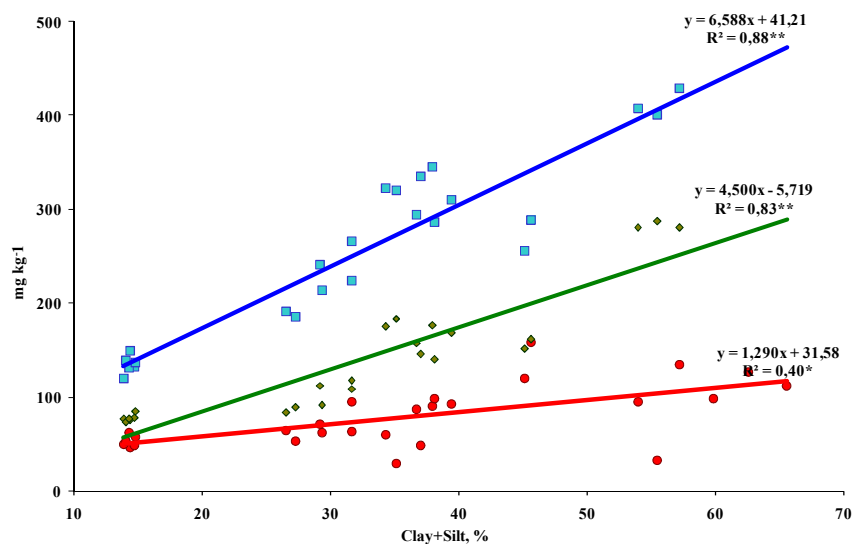


Fig. 2. Organic (Po, red), inorganic (Pi, green) and total (Pt, blue) phosphorous contents in fine fraction (0- 100 μm) versus percentage of clay and silt (n=27)

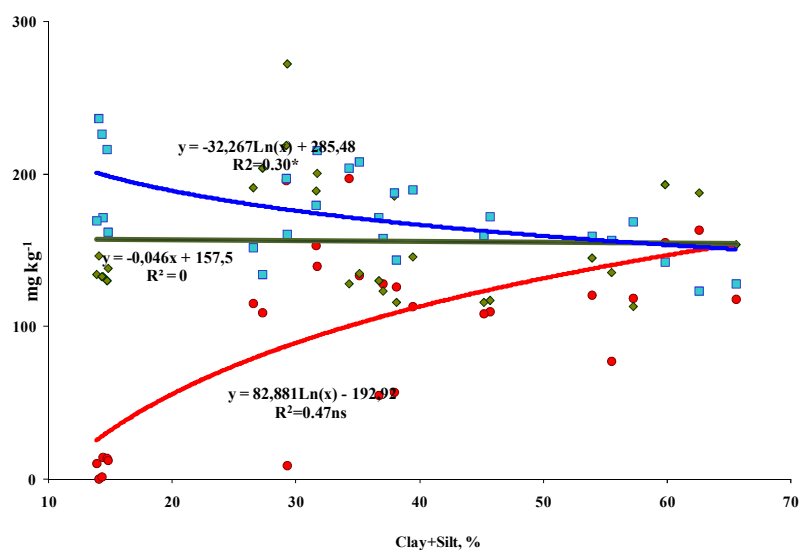


Fig. 3. Organic (Po, red), inorganic (Pi, green) and total (Pt, blue) phosphorous contents in coarse fraction (100 μm -2 mm) versus percentage of clay and silt (n=27)

ones, the present findings could indicate enrichment in Po in the coarse fraction of finer textured soils, as was subsequently corroborated by analysis of the non-weighted results.

Such enrichment gives rise to improved retention of humidity and nutrient supply to crops by the smaller minerals (lime and clay) and their associated organic matter [17].

3.4 Relationship between the Different forms of P and Availability

The contribution of each of the soil fractions was determined by correlation with Pe, following the most frequently used diagnostic tool in the study region for assessing P availability (Fig. 4). The correlation between soil Pi and Po and Pe was low ($R^2 = 0.24$ and $R^2 = 0.19$ respectively, $p < 0.05$), though Pt content accounted for 60% of the variation in P. Although Pt content is one of the determinants of P availability, not all fractions

contribute in a similar way. The Pi in the fine fraction showed a significant correlation to Pe ($R^2 = 0.50$; $P < 0.01$) (Fig. 5). Previous studies have shown that P extracted by the Bray and Kurtz method [36] could have a predominantly inorganic origin [47]. The findings of the present study confirm this observation and are even able to identify the precise origin: the <0.1 mm inorganic fraction.

Pe increased concomitantly with increases in Po, particularly in the coarse fraction. The correlations were low because of the dispersion of data (Fig. 6), which could be due to the variability of particulate organic matter (residues at various stages of decay), the variability of the determination of Po, and the effect of texture on the P content in OM. Soil Po accounted for 19% of the variability in Pe, corresponding mainly to the coarse fraction.

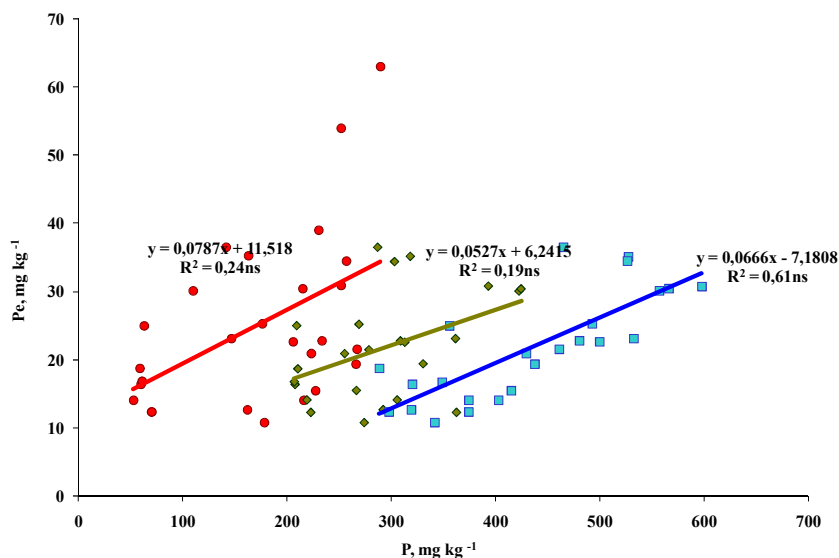


Fig. 4. Relationships between extractable P and organic (Po, red), inorganic (Pi, green) and total (Pt, blue) phosphorous contents in soil (n=27)

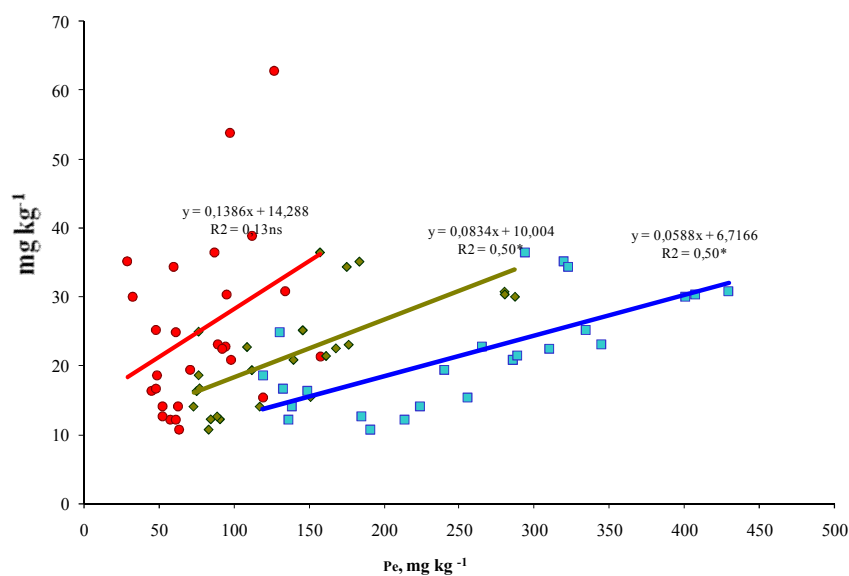


Fig. 5. Relationships between extractable P and organic (Po, red), inorganic (Pi, green) and total (Pt, blue) phosphorous contents in fine fraction (n=27)

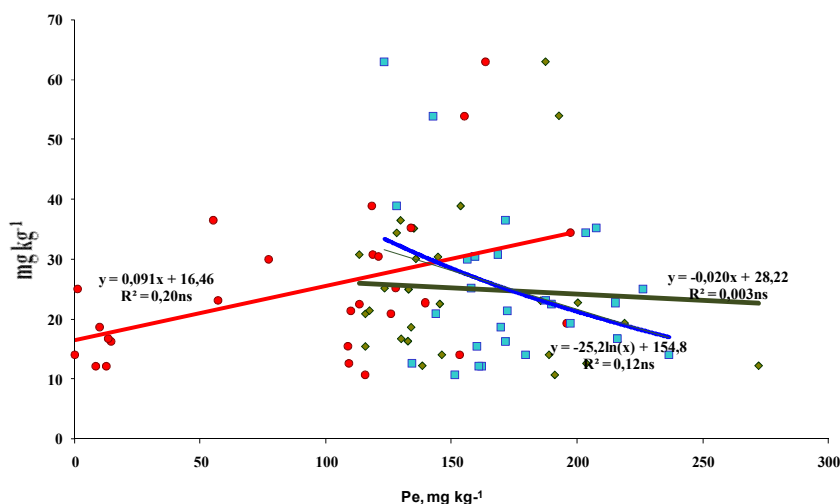


Fig. 6. Relationships between extractable P and organic (Po, red), inorganic (Pi, green) and total (Pt, blue) phosphorous contents in coarse fraction (100 μm -2mm) (n=27)

Soil organic carbon (SOC) associated with MOM and POM correlated more closely with Pe than in the case of their respective P contents (Po in the fine and coarse fractions, respectively, Fig. 7).

The differences observed could be the consequence of the above-mentioned variability in the determination of Po. Furthermore, there is no parallelism between the mineralization of Po and SOC as there is between OC and N (Salas et al. [9]), and stabilization mechanisms of P in SOM are different from those of the other elements [6,46].

The correlations between the Po present in the fine and coarse fractions and Pe were low, suggesting a low contribution by the P present in SOM to availability of this element, particularly in finer textured soils. However, there was a significant correlation between Pe and the organic fractions associated with the fine and coarse fractions, with relatively high coefficients ($R^2 = 0.45$ and $R^2 = 0.56$, respectively $p < 0.01$).

These apparently contradictory results suggest that P availability depends not on P content in SOM, but rather on the content of the organic fractions. Previous studies have shown the important role of microorganism activity in the cycle of nutrients, especially P [48,6]. It can therefore be hypothesized that SOM content is related to P availability by virtue of its importance as a source of food for microorganisms, not by virtue of its content in this nutrient [49].

Even though Pe is widely used as an estimator of P availability in Argentine production system, its close correlation with inorganic fractions could underestimate the contribution of organic fractions during mineralization mainly in sandy soils.

Confirming the data using principal components arrives to similar conclusions (Fig. 8), principal component 1 (CP1) is the one linked to soil texture component, which would explain most of the variability of the P forms in the soil. Therefore the greater variability between the content of different forms of P are explained by sand or clay + silt variables. The sand content, without P, was responsible of soil P and the equilibrium among different P fractions. The Pe, Po- and Pi-MOC contents, similarly to MOC, is more associated with the content of clay and silt. In other hand Pi-POC is not associated with any variable.

Regarding principal 2 (CP2) indicates that Pocl have opposite behavior from MOP, the higher the content of Pocl on the soil will be lower the amount of P present in OM.

3.5 A Conceptual P Model

Abundant research shown that physical fractionation by particle size is useful for studying chemical structure of soil organic matter and its dynamics. Soil organic fractions, and its P contents, within the sand fraction are allocated to the labile pool and soil fractions in silt and clay fractions to the intermediate and passive pools [29,50]. On the other hand, inorganic minerals of

the coarse fraction can be considered a passive pool of P, while the P present in the fine fraction represents an active pool.

According to this finding, a conceptual model can be proposed (Fig. 9), where P could be linked to SOM fractionation schemes.

The principal flows in this model are a) physicochemical and weathering processes, which produce the size reduction of coarse minerals, when mineral particles reach a size

lower than 50 µm are included in the fine fraction; b) humification, organic inputs are transformed to more complex molecules with a lower size; c) mineralization, decomposition of POM and MOM produce nutrient liberation, labile organic matter P could be an important source for plants which is undetected by Bray & Kurtz method d) physic-chemical equilibrium, e) plant uptake, the plants uptake P from the soil solution; f) recycle P, crop residue returned to soil can improve Po by a POM increase.

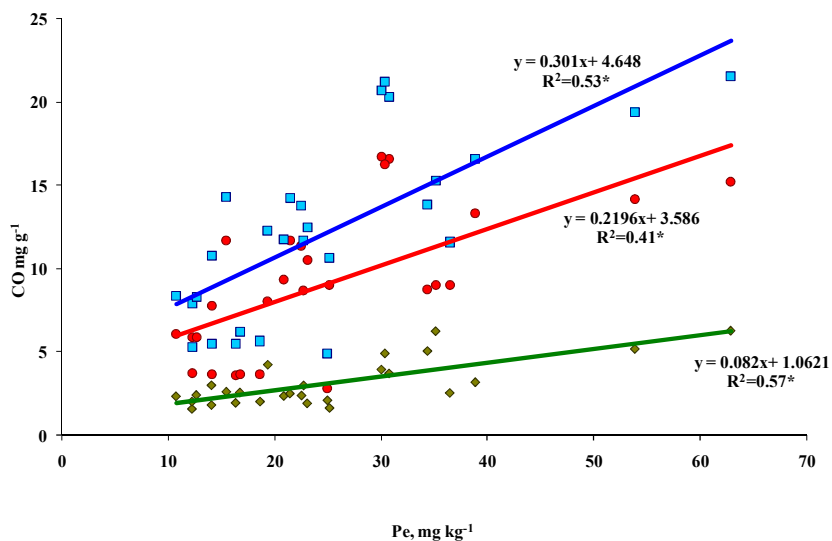


Fig. 7. Relationships between extractable P and mineralized (red), particulate (green) and total (blue) organic carbon (n=27)

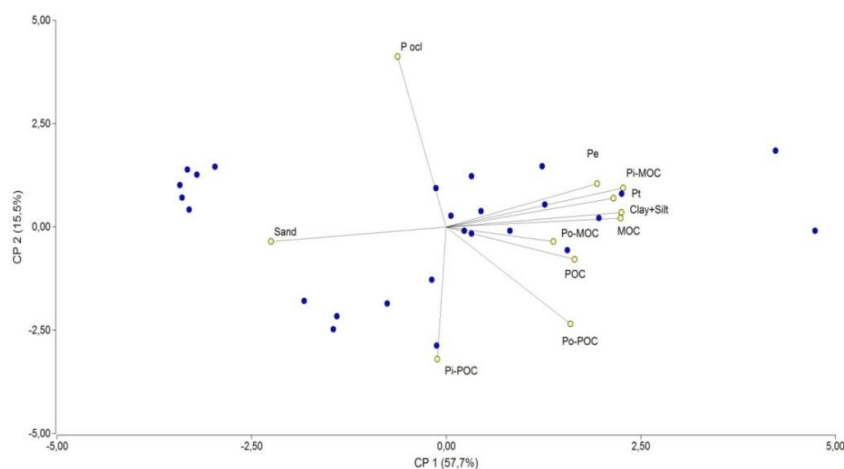


Fig. 8. Main values (n=27) of principal components (CP1 and CP2) for different P forms. Percent of explained variance in parentheses

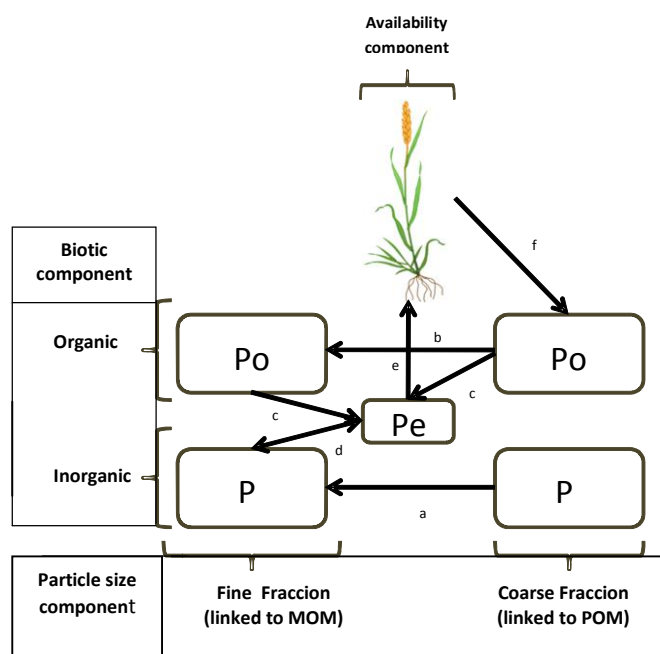


Fig. 9. Conceptual model of P forms and dynamics in soil-plant system

4. CONCLUSION

Texture determines P reserves and the equilibrium of its different forms in the soils of the region under study.

The available P, estimated with Pe content, comes predominantly from the inorganic pool and it is associated to the fine fraction of the soil.

The level of Po is higher in the coarse fraction of soils with a higher content of fine fractions.

Phosphorus content in its different forms is closely associated with soil size fractions. Size fractionation of SOM and P forms determination can be in a conceptual model to a better understanding of soil P equilibriums.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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