Moisture and temperature effect on soil phosphorus availability

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P. ZALBA, O. BRAVO, M. GARAY and N. PEINEMANN
Departamento de Agronomía, Universidad Nacional del Sur, (8000) Bahía Blanca, Argentina.
E-mail address: pzalba@uns.edu.ar

SUMMARY. - The effect of desiccation temperature upon soil phosphorus availability was evaluated under laboratory conditions in soil samples of different texture. Soil samples of 1.4 g were weighed in 25 mL glass tubes and desiccated in an oven at 40, 60, 80 and 100^{o} C using 2 different moisture levels: dry and wet. A total of 10 treatments were carried out with two replicates per treatment. Soil variables analyzed were: extractable phosphorus (Pe), organic phosphorus (Po), pH, organic carbon (OC), soil microbial activity (SMA), $CaCO_3$ and texture (sand, silt and clay %). A marked increase in Pe was observed through the combined effect of moisture and temperature. Medium- and fine-textured soils showed higher Pe increments than coarser-textured soils. Whereas in medium-textured soils (loam) the increment in Pe varied between 4 mg kg^{-1} and 8 mg kg^{-1} as a result of the effect of temperature and temperature plus moisture, respectively, in the case of fine- and coarse-textured soils (clay loam and loamy sand) the increment was between 1 mg kg^{-1} and 6 mg kg^{-1}. The soil variable analysis did not show any statistically significant relationships for Pe. However, high correlations were found between Po and SMA ($r = 0.73$, $P < 0.01$) and between SMA and silt content ($r = 0.86$, $P < 0.01$) . Thus, the results infer that soil microorganisms play an active role in the process of Po mineralization and the consequent increase in Pe.

INTRODUCTION. - Soil sample desiccation usually affects the content and determination of available P in soils. Although it is accepted that soil samples should be air dried, the temperature selected in the laboratory to dry humid samples from the field can lead to a significant degree of error in calculating extractable P in agricultural soils. Numerous soil tests have been developed to evaluate P availability indices; however, the amount of P found in the soil depends among other factors on the type of extractant used, the humidity or dryness conditions in the field, the desiccation procedure used in the laboratory, and the handling of the soil samples during the different seasons of the year. In the field, desiccation and humidifying processes may play an important role in increasing soil phosphorus availability. The soils of the semi-arid region of the Argentine pampas are frequently subjected to considerable changes in water content and temperature mainly at the upper soil surface horizon. These variations in moisture and temperature occur not only from one season to another but also from one hour to another during the same day, possibly giving rise to P mobilization and/or fixation processes in soils. Furthermore, the activity and growth of microorganisms is restricted by soil environmental conditions such as temperature, moisture, pore-size distribution and nutrient availability (Petersen *et al.*, 2002). Soil moisture and soil temperature are likely to contribute to the temporal variability in Pe and should therefore be taken into consideration in analytical determinations on agricultural soils.

Very few studies contain recommendations on the conditioning of soil samples for P determination, and only information on standardized techniques is available. Some comments and recommendations on the effect of soil desiccation in acid soils have been published (Jackson, 1964) but no attempt has been made to understand the natural processes involved. The aim of the present study is to determine and quantify under laboratory conditions the effect of moisture and temperature on soil phosphorus availability in soil samples from a wide region of the province of Buenos Aires in Argentina. To this end, relationships between P availability and physicochemical soil properties such as pH, organic carbon, organic P and texture were analyzed.

MATERIALS AND METHODS. - *Site Description.*- This study was carried out over an extensive region of the province of Buenos Aires in Argentina, covering mainly the central-southern Pampa region. The dominant soils of the region are Mollisols which were first put to agricultural use about a century ago after being cleared of their natural vegetation (deciduous forest and grassland). Mean annual temperature and rainfall varies from 14,1 to 15,2 ^{o}C and from 530 to +800 mm respectively as can be seen in Fig. 1. The climate characterization of the region under study is temperate, continental semiarid to subhumid. Grain crops such as wheat, corn and sunflower, forage crops such as oats and sorghum and perennial grasses like alfalfa and fescue are commonly cultivated in the region.

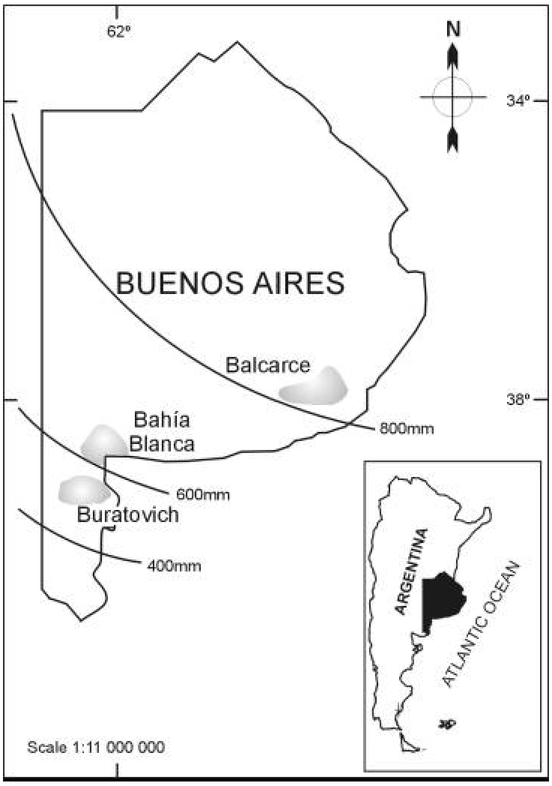

FIG. 1.

Soil Sampling and Treatments. - Pooled samples consisting of 40 to 50 single samples of soil for each 20 to 30 ha were collected from A horizons at a depth of 16 cm using a cylindrical sampler. In total 25 soil samples were analyzed, 8 corresponding to the Balcarce region, 8 to the region of Bahía Blanca and 9 to the region of Mayor Buratovich. Soil samples from the field were air dried at 20°C and sieved through a 2 mm mesh, after which 1.4 g of soil were weighed into 25 mL glass tubes and desiccated overnight in an oven at 40, 60, 80 and 100°C constituting 5 treatments including the air-dried control. Another 5 "wet treatments" were obtained by moistening 1.4 g of air-dried soil with distilled water up to saturation and maintaining soil samples humid during 72 h at 20°C. For the purposes of comparison, the wet treatments were desiccated in an oven at 40, 60, 80 and 100°C, making a total of 10 treatments including the wet control reference treatment. Two replicates per treatment were carried out.

Chemical Determinations. - Extractable phosphorus (Pe) was determined according to the Bray & Kurtz No 1 methodology commonly used in Argentina (Bray and Kurtz, 1945). Slightly alkaline soil samples were carefully selected in order to be able to compare P availability levels before and after desiccation in the oven. Total organic P (Po) was determined by the ignition method (Saunders and Williams, 1955). The pH was measured in H_2O using a glass electrode at a soil-solution ratio of 1:2.5. Soil OC was analyzed according to the modified Mebius method (Nelson and Somers, 1982). Fine particle size fractions were extracted by the pipette technique and sand fractions were separated by sieving. To determine soil microbial activity (SMA) CO_2 emission was measured in a laboratory incubation with 30 g of soil at field capacity. Soil samples were incubated at 28^oC during 3 days . The amount of CO_2 realized was trapped in 25 mL of 0.1 M NaOH and precipitated as $BaCO_3$. The results were expressed as mg CO_2 kg^{-1} d^{-1} (Anderson, 1980).

Statistical Analysis. - The variables were analyzed by simple ANOVA and comparison of means. The difference between treatment P values and the reference air-dried value were analyzed (before and after desiccation in the oven). These differences were compared by the "t" test with probability levels of 5% and 1%. Correlation and simple regression analyses were carried out on the variables selected by their coefficient of determination and adjustment of residuals (Steel and Torrie, 1980).

RESULTS AND DISCUSSION. - Soil samples were grouped according to three textural classes (Table 1): group A includes soils with a sand content higher than 70% (textural classes loamy sand to sandy loam), group B are soils having a 30 to 48% silt content (loam texture) and group C are finer textured soils (textural classes sandy clay loam to clay loam).

TAB. 1. - Physicochemical composition of studied soil groups.

	Group A (coarse texture)	Group B (medium texture)	Group C (finer texture)
Textural Class	loamy sand to sandy loam	loam	sandy clay loam to clay loam
Sand (g kg^{-1})	787 ± 50*	389 ± 53	340 ± 137
Silt (g kg^{-1})	132 ± 41	382 ± 45	404 ± 121
Clay (g kg^{-1})	81 ± 15	229 ± 19	256 ± 42
pH	7.8 ± 0.33	6.8 ± 0.73	7.3 ± 1.01
Organic Carbon (g kg^{-1})	9.1 ± 2.2	25.6 ± 8.2	26.0 ± 7.16
Extractable P (mg kg^{-1})	17.4 ± 10.1	22.7 ± 11.2	15.4 ± 2.7
Organic P (mg kg^{-1})	87 ± 15	218 ± 70	229 ± 71
Soil Microbial Activity (mg kg^{-1} d^{-1})	147 ± 35	304 ± 33	315 ± 50
$CaCO_3$ (g kg^{-1})	5.3 ± 4.1	0.4 ± 1.0	6.1 ± 8.9
Number of Samples	6	12	7

* Mean values ± standard deviation.

Mean values of Pe for the 3 groups of soils according to different moisture and temperature treatments are shown in Table 2.

TAB. 2. - Mean values of Pe (mg kg^{-1}) in dry and wet treatments with increasing levels of desiccation temperature.

		Temperature (°C)				
		20	**40**	**60**	**80**	**100**
Group A	Air-dried	17.4 a*	17.1 a	19.0 a	18.6 a	19.8 a
	Wet	17.7 a	18.9 a	20.1 a	21.6 a	21.4 a
Group B	Air-dried	22.7 a	23.2 a	25.0 a	26.0 a	27.5 a
	Wet	22.2 a	28.1 b	30.2 b	32.9 b	33.0 b
Group C	Air-dried	15.4 a	15.1 a	16.1 a	16.4 a	17.0 a
	Wet	14.8 a	18.7 a	19.5b	21.9 b	22.0 b

* Within the rows, means followed by the same letter are not significant (Tukey, P< 0.05).

No differences in Pe as a function of temperature were detected in any of the 3 groups in the “air-dried” treatment (P >0.95, P> 0.16 and P> 0.38 for the groups A, B and C respectively). In the case of the moistened samples Pe was found to increase with increasing temperature in the medium and fine textures. No differences were observed (P> 0.91) in the coarse texture group as regards the effect of temperature plus humidity. Comparing the same temperature within each textural group, Pe increased in the wet samples as of 40 °C in both the medium and fine texture groups ($P < 0.05$). Coarse texture soil samples on the contrary did not exhibit any significant differences owing to the presence of water ($P > 0.48$).

In order to quantify the increment in Pe liberation relative to the reference situation, differences in matching samples were calculated and compared to the air-dried at 20°C treatment (Table 3).

Significant behavioral differences were found among the three textural groups. It has been demonstrated that the coefficient of diffusion of phosphates depends on the texture of the soil and on the conditions of humidity and temperature (Ming-Gang *et al.*, 1998). The 3 groups exhibit a similar behavior with regard to increasing temperature of desiccation, with low increments in Pe. The largest increments take place as of 40° C and are more marked in soil samples of medium texture; the size of the increase in coarse and fine textured soils is similar. These results are consistent with the observations of other groups indicating that turnover rates of microbial biomass phosphorus (Bp) are related to soil texture (Chen and He, 2002). Figure 2 shows the mean behavior of the three textural groups, the lineal behavior (drying without humidity) being clearly distinguishable from the curvilinear type (drying with humidity).

TAB. 3. - Differences in Pe content among combined treatments of humidity plus temperature vis-à-vis the reference situation (air dry at 20 ^{o}C).

		Dry				**Wet**				
		40 °C	60 °C	80 °C	100 °C	20 °C	40 °C	60 °C	80 °C	100 °C
Group A	Δ	**-0.53**	**0.50**	**1.08**	**1.68**	**-0.45**	**3.12**	**4.27**	**6.53**	**6.78**
(n=6)	**"t"**	NS	NS	NS	*	NS	**	**	**	**
	P	0.10	0.40	0.28	0.05	0.07	0.01	0.01	0.01	0.01
Group B	Δ	**0.76**	**2.24**	**3.03**	**4.05**	**-0.57**	**4.70**	**5.90**	**8.53**	**8.53**
(n=12)	**"t"**	NS	***	***	***	NS	***	***	***	***
	P	0.14	0.001	0.001	0.001	0.19	0.001	0.001	0.001	0.001
Group C	Δ	**-0.37**	**0.64**	**1.03**	**1.56**	**-0.64**	**3.31**	**4.11**	**6.49**	**6.61**
(n=7)	**"t"**	NS	NS	NS	**	NS	***	***	***	***
	P	0.24	0.11	0.21	0.01	0.07	0.001	0.001	0.001	0.001

Δ: Mean difference of Pe between reference treatment (air dried at 20°C) and combined treatments;

" t ": comparison of differences for test t; NS: not statistically different; *, * * and * * * statistically significant at 5%, 1% and 1 ‰ probability level;

P: probability values

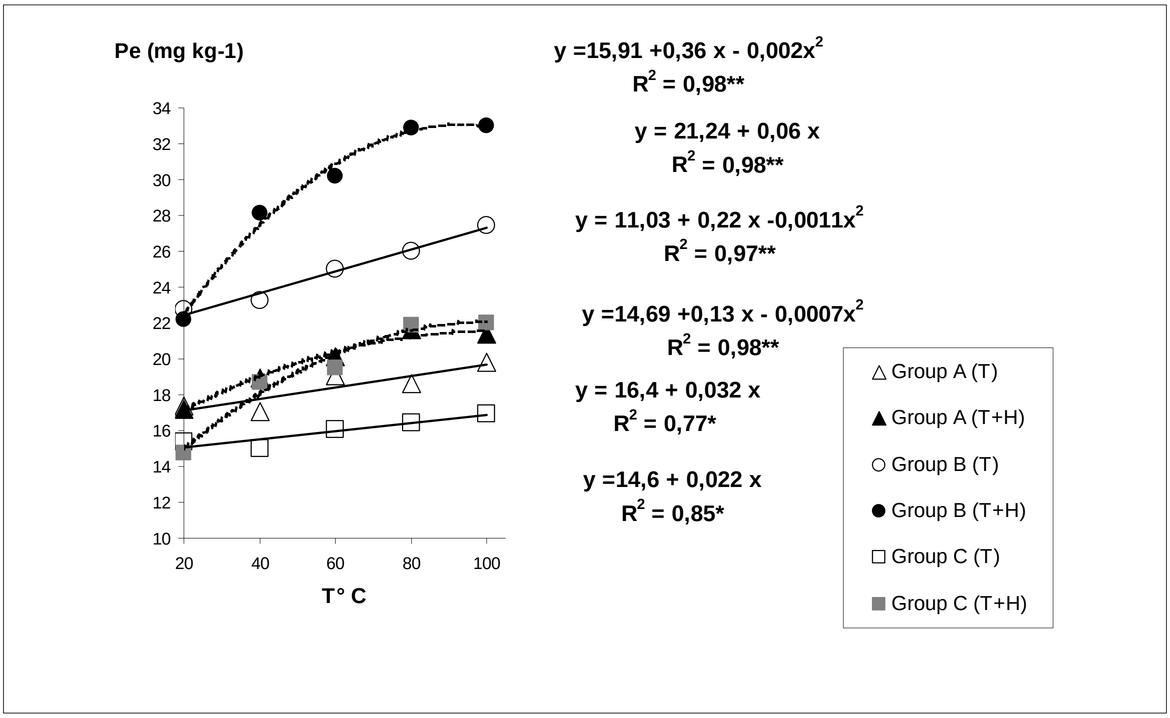

FIG. 2.

The liberation of Pe reaches a maximum value in the wet soil sample and increases at temperatures between 40 and 80 °C. Maximum liberation in all 3 groups is reached at between 80 and 100°C. This behavior is probably due to the mineralization of organic P compounds by soil microorganisms; in groups B and C the level of Po is similar and much higher than in Group A (Table 1). Changes in organic and inorganic soil P fractions induced by laboratory incubation were observed by Hedley *et al.* (1982). Moreover, Petersen *et al.* (2002) found that bacterial phospholipid fatty acids (PLFA) -used for characterizing the living biomass (Tunlid and White, 1992)- increased significantly during a long-term experiment in eastern Washington during growth of spring wheat and that it was sensitive to soil environmental conditions. According to Alexander (1977), Po mineralization is favored by high temperatures, the thermophilic range being more favorable than the mesophilic range. There is evidence that microbial activity plays a major role in redistributing P into different forms in the soil (Hedley *et al.*, 1982).

Soil variables analyzed for the whole population were found not to affect the level of Pe (Table 4). However, a good correlation is observed between OC and Po in the finest mineral fractions of the soil. This behavior enables us to infer that the highest quantities of Pe liberated by the combined effect of humidity and temperature come mainly from soil aggregates and not from single mineral particles of the sand fraction. Other high correlations were found between Po and SMA (r = 0.73, P <0.01) and between SMA and clay content (r = 0.88, P <0.01) .This fact would indicate that finer texture soils rather than coarser texture soils would have a higher microbial activity and also a higher proportion of Po.

TAB. 4. - Correlation values among the analyzed soil variables.

MAP	1.00									
Pe	0.20	1.00								
Po	0.75*	0.27	1.00							
PH	-0.67	-0.23	-0.33	1.00						
OC	0.82	0.24	0.96	-0.44	1.00					
SMA	0.39	0.17	0.73	-0.36	0.71	1.00				
$CaCO_3$	-0.44	-0.24	0.02	0.71	-0.10	-0.02	1.00			
Sand	-032	-0.08	-0.75	0.17	-0.74	-0.90	-0.10	1.00		
Silt	0.21	0.10	0.70	-0.03	0.66	0.86	0.17	-0.98	1.00	
Clay	0.48	0.05	0.77	-0.40	0.81	0.88	-0.04	-0.93	0.84	1.00
	MAP	**Pe**	**Po**	**pH**	**OC**	**SMA**	**$CaCO_3$**	**Sand**	**Silt**	**Clay**

*: correlation values (r) higher than 0.42 are statistically significant at P< 0.05; MAP = mean annual precipitation; Pe = extractable phosphorus; Po = organic phosphorus, SMA= soil microbial activity; $CaCO_3$ = calcium carbonate.

From Table 4 it may also be inferred that the dynamics of Pe do not necessarily depend on the Po or OC content of soil under cultivation or agricultural production. The relationship between carbon content, pH and precipitation is interesting: it is positive for carbon and negative for pH, the highest OC levels being observed in the Balcarce area in combination with the lowest pH values. Despite its significant correlation with MAP, clay content does not show a good fit to the lineal model since it is affected by the different parent materials of the soils.

CONCLUSIONS. - Soil samples from the upper soil mineral horizon of an extensive agricultural region, grouped according to textural class, show differential behavior upon combined treatment with humidity and temperature. Though the coarse texture samples in Group A, where the sand fraction is prevalent, showed no change in P availability as a function of temperature, the response to temperature increased significantly when the soils were moistened. The medium and fine textured samples of Groups B and C , on the other hand, showed a marked response to changes in temperature and humidity, liberating significant quantities of Pe in the combined treatment. In the 3 studied textural groups, the liberation of Pe began at 40° C and reached its maximum between the 80 and 100° C in the case of the moistened samples.

In soils of medium texture the maximum liberation of Pe in response to temperature increase was 4 mg kg^{-1} and for the combined temperature plus humidity treatment, 8 mg kg^{-1}. In the case of coarse and fine textured soil samples the values were 1 and 6 mg kg^{-1} respectively for both textural groups. This leads to the conclusion that the handling of soil samples (humidity at the moment of sampling, drying temperature in the laboratory, sampling season, etc.) introduces an important source of variability in Pe determinations as a function of soil texture. Such variability should be borne in mind in efforts to arrive at a precise evaluation of the real availability of P in agricultural soils.

No relationship could be established between Pe and the different soil variables analyzed, from which it is concluded that the dynamics of Pe do not necessarily depend on Po or OC content in the soil. However, high correlations were found between Po and SMA ($r = 0.73$, $P < 0.01$) and between SMA and clay content ($r = 0.88$, $P < 0.01$). Thus, it can be inferred that Po mineralization and the consequent increase in Pe is regulated by the humidity and temperature conditions of the soil and that soil microorganisms play an active role in this process.

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FIGURE CAPTIONS

FIG. 1. - Geographical location of the study area. The insert depicts the location of the province of Buenos Aires in Argentina.

FIG. 2. - Pe liberation curve for the 3 textural groups as a function of the drying temperature (T) and temperature plus humidity (T + H).