Total Phosphorus Content in Relation to Total Iron and to Carbon Content in Brazilian Oxisols

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Abstract

In Oxisols, 'phosphorus profiles' have been formed which are often strongly dependent on the iron and carbon content of the soils. Four different kinds of phosphorus profiles were recognized, viz. *1) mature profies, 2) phosphorus profiles with a strong accumulation in the surface layer, 3) irregular phosphorus profiles and 4) anthropogeneous enriched phosphorus profiles.*

The results of a statistical study using 421 samples of Oxisols from Brazil are discussed. The relation of total phosphorus with organic carbon and with total iron for all samples studied can be expressed as :

$$P_2O_5 = 0.002 + 0.010C + 0.0007\,Fe_2O_3$$

The regression coefficient for C at the 95% level has confidence limits of 0.0056 and 0.0141 and for Fe_3O_3 of 0.0065 and 0.0075. Notable is the small interval for the regression coefficient of Fe_2O_3.

The deviation in P_2O_5 content of some typical Oxisols is further discussed.

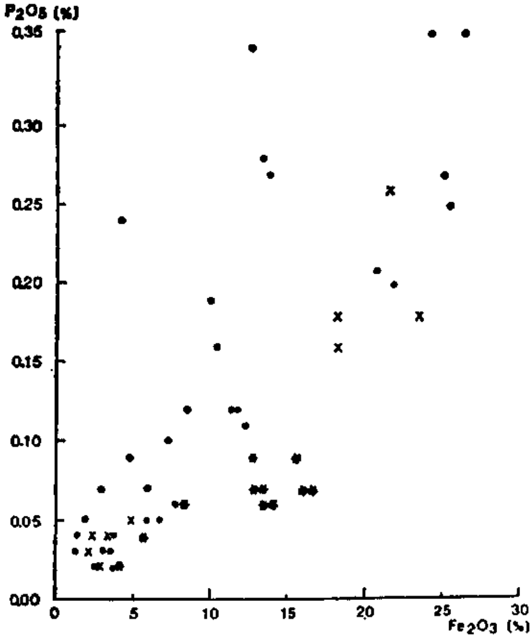
Introduction

This paper deals with the total phosphorus content in relation to the carbon and total iron content. Attention is also given to the "total-phosphorus profiles".

The data used are from Brazilian Latosols. These Latosols are equivalent to the Oxisols in the Soil Taxonomy (Staff Soil Survey, 1975) and to the Ferralsols of the Legend of the Soil Map of the World (FAO-UNESCO, 1971). The data are taken from publications of the Servico Nacional de Levantamento e Conservacao de Solos-Embrapa in Rio de Janeiro, Brazil (Camargo, *et al.*, 1962; Lemos *et al.*, 1960: Lemoos *et al.*, 1967 and from Amazon soils (Sombroek, 1966).

The laboratory methods used have been described by Vettori, 1969 [Total P_2O_5 and total Fe_2O_3 were extracted by H_2SO_4 S.G. 1,47. Carbon was determined with the method of Tiurin using kalium bichromate (0.4N)]. Also some data were used on total P_2O_5 (in Figure 1) determined with rontgen-fluorescence at the Soils Department of the Agriculture University.

This study includes results from two MSc theses at the University at Wageningen (Grafhorst, 1972 and Treep, 1973).



Total P_2O_5 related to total Fe_2O_3 for Oxisols (x), Oxisols cerrado (●) and other soils (•)

Figure 1: Total phosphorus in Oxisols.

A preview (in the Portuguese language) of a part of this paper was given as a general lecture at the Congress of the Brazilian Society of Soil Science (Bennema 1974).

General

The fate of phosphorus in soils is as we know quite different from that of the bases calcium, nagnesium and potassium, because the phosphorus is fixed by the soil mass. This does not hold however for all the phosphorus, as follows from the presence of phosphorus in river-water and in the sea, which amounts to 3.5 million tons phos phorus each year (Epstein, 1972). A part is obviously leached.

The general picture is that P_2O_5 is partly leached from the parent material and the soil material but that free Fe_0O_3 and other soil constituents like free Al_2O_3, CaO_2 and organic matter fix the P_2O_5, which hinders the leaching. The process of leaching will especially act in the first stages of weathering and will become less and less active when the soil is more weathered, because the remaining phosphorus will consist more and more of phosphorus which is perfectly fixed. Occluded Fe phosphate seems in particular such a form of strongly fixed phosphorus (Chang and Jackson, 1958).

It may be expected that in strongly weathered soils the total P_2O_5-content is related to the free Fe_2O_3 content and to the organic matter content, at least if strongly weathered means also a total weathering of the primary phosphorus containing minerals. This assumption is however not always true, as traces of apatite may still be present in some soils regarded as strongly weathered soils. Figure 1 shows the P_2O_5-content of the samples of Oxisols and other soils in relation to Fe_2O_3 content.

Very low and low P_2O_5 contents are almost absent if the Fe_2O_3 content is medium or high.

A distinction is made in the graph between samples of Oxisols (indicated with x) and those of other, mostly less weathered, soils (indicated with a point). It is obvious from the figure that the Oxisols have in general a lower P_2O_5-content than other soils with the same Fe_2O_3-content. The graph shows further that for the younger soils no linear relation exists between P_2O_5 and Fe_2O_3, but that such a relation might be present for the Oxisols. The data for the other soils in the figure are very scattered, but those of the Oxisols tend towards a linear relation of P_2O_5 = 0,007 Fe_2O_3

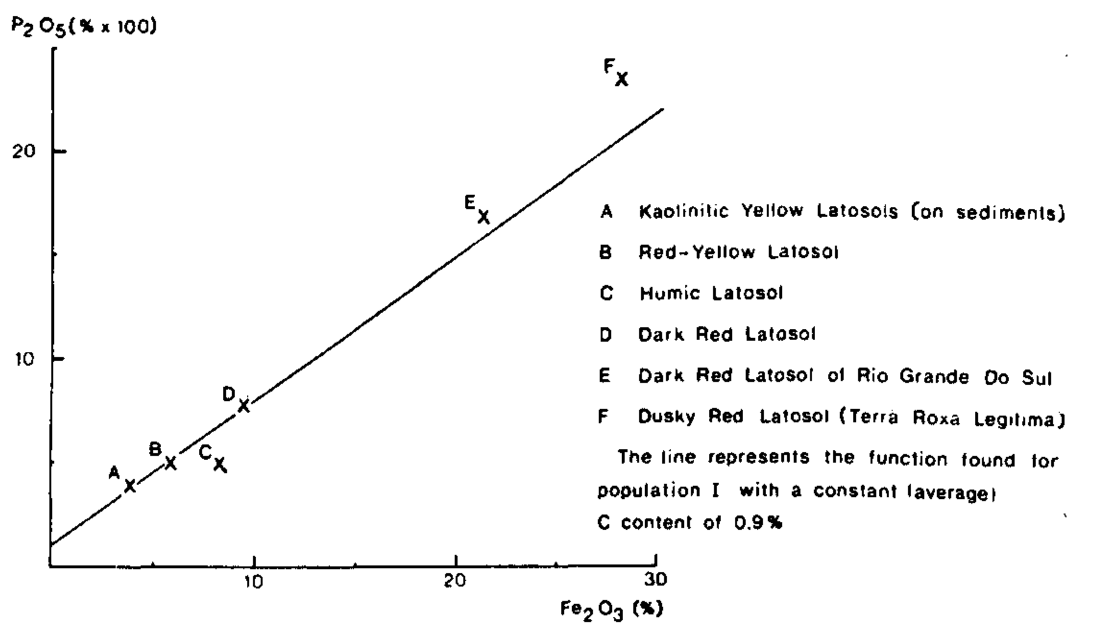
The separation of the different Latosols in Brazil is mainly based on soil color, which in turn is related to iron content. It is therefore to be expected that the total phosphorus content of the different Latosols will also differ. This is indeed the case as is shown in Figure 2. We can observe from this graph that the differences in soil color for the classification of Latosols as have been done in Brazil and also in the legend of the Soil Map of the World (FAO-UNESCO 1971) seems not to be without significance.

Phosphorus Profiles

A study of the "total-phosphorus profiles" of Brazilian Oxisols revealed that four different kinds of phosphorus profiles can be recognised on the basis of differences in the change of total phosphorus with depth or in other words on the phosphorus profiles. The general level of the phosphorus content, which is strongly correlated with the Fe_2O_3 content is hereby not taken into account. Examples of different kinds of phosphorus profiles together with other relevant information can be found in Table 1. The four kinds of phosphorus profiles recognised are:

1. Mature P_2O_5 profiles with a small decrease from the topsoil downwards (see profile 1, Table 1). The P_2O_5 content seems to be linearly correlated with C and Fe_2O_3 content. A variant is formed by P_2O_5 profiles in which the phosphorus content does stay the same downwards together with the presence of only low amounts of organic matter in the topsoil (see profile 2, Table 1).

2. Phosphorus profiles with an "excess" of phosphorus in the surface layers (see profile 3, Table 1). This is only the case with some of the Oxisols derived from basaltic rocks under a natural savanna (cerrado) vegetation. The amount in the topsoil is much higher as one would expect on base of iron and organic matter content. The cause of this high phosphorus content



Relation of the average P_2O_5 contents with the average Fe_2O_3 contents of five different groups of Latosols

Figure 2: Total phosphorus in Oxisols.

TABLE 1. FOUR DIFFERENT KINDS OF DISTRIBUTION OF % TOTAL P_2O_5 IN OXISOL (LATOSOL) PROFILES.

	1 Dark-Red Latosol Furnas 9					2 Red-Yellow Latosol of medium texture Sao Paulo 52				
	Depth (cm)	P_2O_5 present (%)	P_2O_5 calculated (%)	Fe_2O_3 (%)	C (%)		Depth (cm)	P_2O_5 present (%)	P_2O_5 calculated (%)	Fe_2O_3 (%)	C (%)
A1	0-5	0.11	0.10	12.6	2.33	A1	0-30	0.03	0.02	2.5	0.71
A3	5-32	0.11	0.10	12.7	1.74	A3	30-64	0.03	0.02	2.7	0.45
B1	32-83	0.10	0.10	13.0	1.03	B1	64-166	0.03	0.02	2.6	0.32
B21	83-150	0.09	0.09	13.2	0.58	B22	166-391	0.03	0.02	3.0	0.16
B22	150-190	0.08	0.09	13.5	0.34	B23	391-509	0.03	0.02	3.1	0.13
	3 Dusky-Red Latosol (Terra Roxa Legitima) Sao Paulo 38						4 Dark-Red Latosol Sao Paulo 41				
A1	0-20	0.45	0.23	31.9	2.0	A1	0-20	0.13	0.08	10.1	0.93
A3	20-58	0.30	0.23	33.2	1,3	B1	20-50	0.15	0.08	11.3	0.67
B21	58-228	0.25	0.23	32.9	0.9	B21	50-120	0.15	0.08	11.4	0.50
B22	228-260	0.21	0.22	32.1	0.4	B22	120-180	0.13	0.08	11.9	0.29

Mostly the P_2O_5 present decreases a little with depth (1) or stays the same (2).
Some Oxisols on basalts (3) show a relatively great decrease of P_2O_5 with depth. Profile 4 is an example of an irregular profile with a small increase from A to B and with a small increase from B21 to B22.

is not known. It could be that fixation in the topsoil is for some reason or other stronger than normal. The P_2O_5 pumped up by the vegetation would in this case accumulate more strongly in the topsoil than normally.

3. Irregular (young) phosphorus profiles (see profile 4, Table 1) with a small increase in P_2O_5 downwards. This increase is not related to Fe_2O_3 or Carbon content.

4. Irregular phosphorus profiles due to enrichment as present in the "Black Soils of the Indians", which are found in the Amazon region. The level of phosphorus is also often very high.

These "Black soils of the Indians" have in their extreme form an anthropogenous epipedon. They are relatively rare and will further not be taken into consideration.

The different phosphorus profiles can be seen as genetic pedological features which did not till now get the attention they deserve. In relation to the genetic aspect the question is how far the original phosphorus contents of the rocks play a dominant role in the mature profiles. Is the strong correlation found between P_2O_5 content and Fe_2O_3 content possible because the original P_2O_5 content is already related to the initial Fe_2O_3 content or is another mechanism present which makes the ultimate P_2O_5 content independent of the original content present in the rock. It should be recognised that the soils studied are very old soils indeed. The soil materials as such are often hundreds or thousand years old. This means that the rainfall brought large amounts of phosphorus in the soil (each year 0.3 kg/ha means 30.000 kg in 100.000 years). The yearly gain of 0.3 kg/ha will ultimately lead to a situation in which the distribution of phosphorus is related to the fixing power of the soil independent of the original contents.

Total Phosphorus in Relation to Total Iron and Carbon

A further study was made of the correlation of total P_2O_5 with total Fe_2O_3 with free Al_2O_3 (estimated by calculation) and with organic carbon content.

It was remarked already that some soils belonging to the Terra Roxa legitima (Dusky-Red Latosols) have "abnormal high P_2O_5-contents", especially in the top layers. The samples of these Terra Roxa Lagitima soils were therefore not included in the first part of the study. The samples which were used in the first part form population I. In Tables 2 and 3 results of this study are given for population I and also for a population II in which some samples of population I are omitted.

A highly significant relation between P_2O_5 and Fe_2O_3 content and also between P_2O_5 and organic carbon content was found. A correlation with free Al_2O_3 content could not be proved.

These correlations were also calculated for different soil groups: Dusky-Red Laotosls, Dark-Red Latosols, Red-Yellow

TABLE 2. CORRELATION COEFFICIENTS OF PHOSPHORUS WITH CARBON, IRON OXIDES AND GIBBSITE

	population I	population II
P_2O_5 – C	0,320	0,413
P_2O_5 – Fe_2O_3	0,814	0,935
P_2O_5 – free Al_2O_3	– 0,046	– 0,088
P_2O_5 – free $Al_2O_3 \times Fe_2O_3$	0,087	0,075
P_2O_5 – C, Fe_2O_3	0,825	0,940

TABLE 3. RESULTS OF REGRESSION ANALYSES ACCORDING TO THE GENERAL FORMULA:
$\% P_2O_5 = \text{constant} + a \times \% C + b \times \% Fe_2O_3$

population I	population II
$P_2O_5 = 0,0016 + 0,0098\,C + 0,0070\,Fe_2O_3$	$P_2O_5 = 0,0016 + 0,0081\,C + 0,0072\,Fe_2O_3$
confidence limits at 95% level	
$0,0056 < a < 0,0141$	$0,0045 < a < 0,0117$
$0,0065 < b < 0,0075$	$0,0068 < b < 0,0075$
standard error	
0,031	0,019

Latosols and Yellow Kaolinitic Latosols. These groups are based, as the names indicate, on colour differences. These colours are directly related to iron contents. The correlation between P_2O_5 and Fe_2O_3 contents could not be studied adequately in such groups because the variability of the Fe_2O_3 in one group becomes too small. The use of these groups for further study was therefore rejected.

The function found for population I: $P_2O_5 = 0.0016 + 0.0098\ C + 0,0070.\ Fe_2O_3$ gives a general trend. There are however many exceptions for single samples in which the P_2O_5 is considerably lower or higher than the formula indicates. The calculated values can in such cases be used as a reference and the question can be put why some samples have considerably lower or higher contents as the formula indicates.

Soils with an irregular phosphorus profile (profile type 3) have, as was expected, higher values as the calculated ones. For profile 4 in Table 1 respectively 0.13-0.15% and 0.08%. These higher values are assumed to be due to unweathered phosphorus containing minerals.

One of the five Humic Latosols used for this study has an irregular phosphorus profile and contains traces of apatite. The samples from this profile have a relatively high content of P_2O_5. The samples of the other four profiles show however relatively low P_2O_5-contents (see also Figure 2 under C). The fixation of P_2O_5 seems to function less perfectly in this kind of soil.

The samples of the profiles of Terra Roxa Legitima of the cerrado and especially the topsoils of these profiles have, as was expected, a much higher P_2O_5-content than the function indicates.

In Table 1 in profile 3, 45% P_2O_5 present and the calculated value is 0.23%. We find, if we calculate the amount of P_2O_5 in correlation of C and Fe_2O_3 for this group apart, a very high regression-coefficient between P_2O_5 and C ($P_2O_5 = 0.160 + 0.124\ C - 0.001\ Fe_2O_3$). This does not mean of course that the organic matter has such a high P_2O_5-content (would be about 20% N in the organic matter). The higher concentration of P_2O_5 in the topsoil should be seen as a function of the organic cycle as is also the case with organic carbon. P_2O_5 and C are thus both accumulated in the topsoil due to this cycle but P_2O_5 need not be necessarily present to a large extent in organic form.

It is known from fertilizer studies that Terra Roxa Legitima soils may give a strong reaction to phosphorus and also to liming (Mikkelsen 1963), but that their joint effect of each separately. This is seen as an indication that the availability of P_2O_5 increases, due to liming. We might expect, that especially in the Terra Roxa Legitima's with P_2O_5 in excess in the topsoil such a favourable reaction on liming will occur.

Using the function as a reference, it appears, as follows from the foregoing, that certain soils do not belong to the normal population. The data of the profiles which were assumed to belong to the normal population were used to calculate again the relation of P_2O_5 with Fe_2O_3 and with carbon content. The function found: $P_2O_5 = 0.0016 + 0.0081\ C + 0.0072\ Fe_2O_3$ is not greatly different from the function for population I. The confidence limits for the coefficients of regression are however narrower and the standard error is lower (see Table 3).

Discussion

The regression-coefficient of the organic carbon is around 0.01. This does not necessarily mean that each gram C is accompanied by 0.01 gram P_2O_5. We already got a warning against this kind of conclusion from the extremely high regression-coefficients in the case of the Terra Roxa Legitima. Organic matter decreases with depth. A decrease in depth of P_2O_5 not bound to organic matter, will still show a correlation with organic matter. A tentative study was made of the influence of depth by comparing the deviations of the calculated and the measured percentages of P_2O_5. It appeared that these did show some relation to depth. In the upper layers the deviations are more positive, in the lower layers more negative, notwithstanding a part of the influence of depth might already be accounted by the correlation of P_2O_5 with organic matter. This problem has to be further explored. The amounts of P_2O_5 correlated with one gram organic matter or with one gram Fe_2O_3 are almost the same. The percentage of Fe_2O_3 vary however much more in the different soils and the percentages are mostly higher. The correlation-coefficient of P_2O_5 with Fe_2O_3 is therefore higher than for P_2o_5 with C. The differences in P_2O_5-percentages are often not expressed in the available phosphorus content, because the soils with the highest amounts of total phosphorus will have often also the highest fixing power. In some instances however, the higher amounts of total phosphorus might still have a practical significance for plant life. Some tree species, especially those with mychoriza like Pinus Eliottii, might be able to use a part of the fixed P_2O_5 We saw further already that with liming a small part of the P_2O_5 in some cases might become available.

This has however bearing only on part of the P_2O_5. It is a strange and unacceptable thought that on so many red tropical soils either the plant production stays low due to deficiency of P_2O_5 or heavy applications of P_2O_5 are to be given while at the same time the total content of P_2O_5 in the soil is very high in relation to what is needed (*e.g.* 3000 kg/ha present). It seems, however, that this problem is not involved as far as our knowledge goes today.

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