Effects of parent material and land use on soil phosphorus forms in Southern Belgium

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Abstract
Appropriate management of soil phosphorus fertility should rely upon sound knowledge about the phosphorus reserve and its bioavailability. However, the fate of P in the soil depends on soil characteristics and agronomic practices. The influence of parent material and land use on P content and distribution between organic and mineral pools has been studied. The diversity of pedological contexts in the Walloon Region reflects on soil properties. A large range of P contents has been observed and partially attributed to an effect of parent materials in surface as well as in deeper horizons. Relationships with total Al and Fe contents were observed. Differences among parent materials were observed for available P but not for proportions of organic and inorganic P. Land use had also an influence on P content but only for surface horizons. Pasture soils presented higher P contents than crop soils but lower available P. Other parameters, such as pH or organic matter which depend on land use, also seem to have an impact on P availability. This confirms that the management of phosphorus resources in cultivated soils has to take into account the sub-regional specificities of soil parent materials and land use.

Key Words
Total phosphorus, organic phosphorus, inorganic phosphorus, available phosphorus, fertility.

Introduction
Soil phosphorus faces both environmental and agronomic issues because it is responsible for eutrophication of surface waters and, at the same time, it is an essential element for plant growth. It is therefore important to deepen our knowledge about the quantities and forms of P in soil and hence about the susceptibility to migrate to other compartments of ecosystems. Reserves of P in soil can be divided into organic (P_{org}) and inorganic (P_{inorg}) fractions. The absolute and relative importances of these reserves vary according to environmental conditions. In low input farming systems, the reserves of organic and inorganic P may be a significant source of P to crops (Romanya and Rovira 2009). Actually, when negative balance of P occurs, the availability of P to crops is determined largely by weathering and/or mineralization of soil P reserves. These processes are influenced by soil biota and soil organic matter dynamics. Most P used by plants is taken up in inorganic forms but organic P reserves can represent a large proportion of total P content in soil. According to Fardeau and Conesa (1994), P_{org} represents 25-30% of total P in cultures and up to 75-80% in grasslands and forests. So, P availability to plants depends on (i) the chemical balance of P_{inorg} between the solid phase and soil solution, (ii) the microbial decomposition of plant litter and (iii) the pools of organic P in the soil (Tate and Salcedo 1988). Soil organic P reserves can therefore play a significant role in supplying P to plants. However, a large proportion of organic P reserves may not be readily available to plants (Romanya and Rovira 2009).

There are two main P sources in agricultural soils: the natural geochemical background and the fertilization. Soil forming processes should act on the P fractionation. According to some authors, the P_{org} contents should be higher within well developed soils and P_{inorg} should become less available because of the occlusion of P in minerals. The distribution of soil P between different organic and inorganic forms depends on agronomic practices and soil properties. Chardon and Schoumans (2007) have shown the effect of the soil texture on the P behaviour in soil-sediment systems. The organic matter, clay content or other bounding sites like Al and Fe oxides influence the forms of P. Fertilization practices have also an impact on the forms of P. Romanya and Rovira (2009) have shown that organic P reserves were sensitive to the quantity of P added, rather than to the quality of the input and that organic P reserves were high in the soil that received large amounts of manure.

The evaluation of soil P fractions is essential to determine the P behavior in soils. The objectives of this paper were (i) to evaluate the influence of parent material and land use in soils from Southern Belgium on P content, and (ii) to study the fractionation into organic and inorganic pools.

Materials and Methods

Study Area and Soil Sampling

In order to be representative of the diversity of natural environment in Southern Belgium, twelve types of parent materials were first selected according to their spatial importance and to differences in their properties. For each parental material, a representative area was chosen according to geology, pedology, relief and land use (Figure 1). Within each area, the one to two dominant soil type / land use combinations were selected. Ten parcels from 10 different farms were sampled for each parental material. Soil types were observed on the field after augering and soil samples were taken in surface horizon (0-15 cm) and in the deep 100-120 cm horizon. An intermediate horizon has been sampled in some occasions in order to evaluate P profiles. Finally, 258 samples were collected, 120 surface samples, 120 deep samples and 18 intermediate samples. All the samples have been taken between October and December 2008. They were located in 76 fields, 15 temporary grasslands and 29 pastures.

Chemical Characterization

Samples were dried at 40°C and sieved at 2 mm (an aliquote at 200 µm) prior to storage and laboratory analyses. Some soil characteristics were determined. Particle size distribution was determined by sedimentation according to pipette method. The cation exchange capacity (CEC) was determined by modified Metson method. Total organic carbon (TOC) content was analyzed by Springer-Klee method (ISO 14235, 1998) and pH_{water} (v:v, 1:5) and $pH_{1N\ KCl}$ (v:v, 1:5) according to ISO 10390 (2005). Available phosphorus (P_{av}) was determined following Lakanen-Erviö method (Lakanen and Erviö 1971), and total phosphorus (P_{tot}) was determined after total solubilising by acid attack (NF X 31-147, 1996). Inorganic phosphorus (P_{inorg}) was extracted by addition of 20 ml of H_2SO_4 to 0.5 g of 0.2 mm soil. This mix was brought to the boil during 10 minutes and put in a 100 ml balloon. Then, the solution was filtered and P content was measured. Organic phosphorus (P_{org}) was determined by calculation: P_{tot} - P_{inorg}. After extraction, phosphorus contents were measured by colorimetry (Murphy and Riley 1962). The metals in all extracts (Fe, Al and Ca) were determined by flame atomic absorption spectrometry (VARIAN 220).

Statistical Analyses

The effects of land use and parental materials on soil P fractions were evaluated for each depth, with analysis of variance using the General Linear Model Procedure of MINITAB 15 program. These differences were considered significant at the $p \leq 0.05$ level. A correlation and regression study has also been made between the various parameters to identify significant relationships with phosphorus forms.

Results and Discussion

Soil properties

Large ranges of variation have been observed for studied soil properties. Soil pH_{water} ranged from 4.62 to 8.4, TOC from 0.42 to 9.71%, clay content from 6.2 to 67.2%, and CEC from 2.5 to 71.2 $cmol_c$/kg. These values illustrate the diversity of studied contexts which are representative of diversity within Southern Belgium.

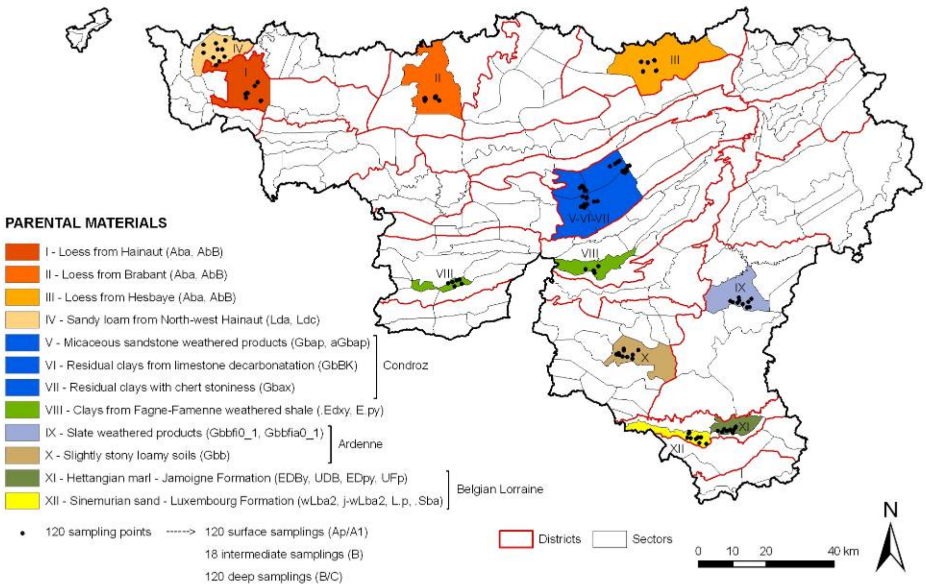

Figure 1. Location of studies samples in Walloon Region.

The soil P_{tot} values ranged from 167 to 2294 mg P/kg, with a mean in surface and deep horizons of 894 and 415 mg/kg, respectively. Leaching is considered as negligible in Southern Belgium, so deep P content can be considered as natural content, resulting from the weathering of soil parent material. The difference between surface and deep content can be attributed to effects of biogeochemical cycle and fertilization inputs. This hypothesis doesn't take into account the possible disturbation due to mesofaunal activity but the importance of these processes seems very difficult to evaluate. On average, deep soil P amounted to half of surface P. Available P represented on average about 9% of the total P in surface horizon. However, this percentage can vary highly according to soil properties.

Effects of parent materials

Parent materials (MP) had a significant influence on P forms and on P, Al, Fe and Ca contents in both surface and deep horizons. A South-North gradient has been observed for P_{av} in Walloon Region, which confirms previous results.

P_{tot} and P_{av} present opposite distributions among parent materials (Figure 2). The lower P_{tot} (MP I to IV), the higher P_{av} content, it could be explained by differences in P sorption capacity. This soil property is very important and varies from one soil type to another. Soil differences can generate different P behaviour. In light textural soils like sandy and silty soils, P is more readily available for plants and for lateral transfers. These areas are the most sensitive for regarding surface water eutrophication.

Effects of land use

Figure 4 illustrates the very highly significant differences of P status within the three studied land uses. In cultivated soils, P_{tot} represented 81% of that in permanent pastures. Differences in P input/output balances, with higher exportations in crop soils, could explain these differences of P status. Similar differences were also observed for other P forms, except P_{av}. The amounts of available P in the cultivated soils were in average 65% and 138% higher than permanent pasture and temporary grasslands respectively. These differences are probably linked to a higher availability of P brought by fertilization products in cultivated soils. Permanent pastures had higher P_{av} than temporary grasslands because manure was brought by animals during the pasturage. This leads to higher P content even if no significant differences can be shown. According to phosphorus forms, temporary grasslands presented similar properties than permanent pastures, except for P_{inorg} which had an intermediate behavior between the two other land uses. Moreover, fertilization practices can vary deeply between parcels according to type of culture and plant exportations. Thus the P_{av} variability in cultivated soils is very important.

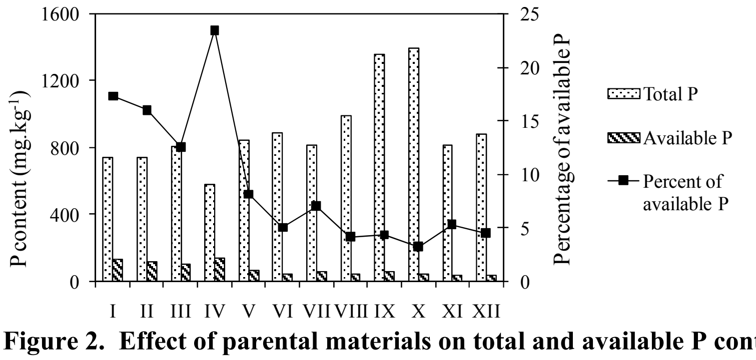

Figure 2. Effect of parental materials on total and available P contents in surface samples.

The P_{org} and P_{inorg} relative importance differed from one parent material to another but these differences were limited (Figure 3). On average, P_{org} represented 25% of P_{tot}, which corresponds to values given by Fardeau and Conesa (1994).

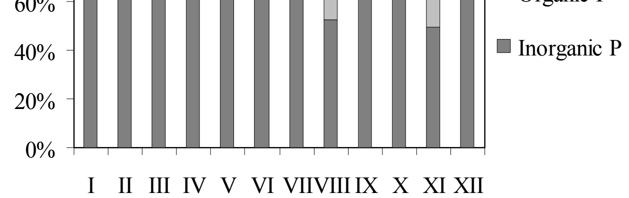

Figure 3. Organic and inorganic P fractions in surface samples grouped by parent material.

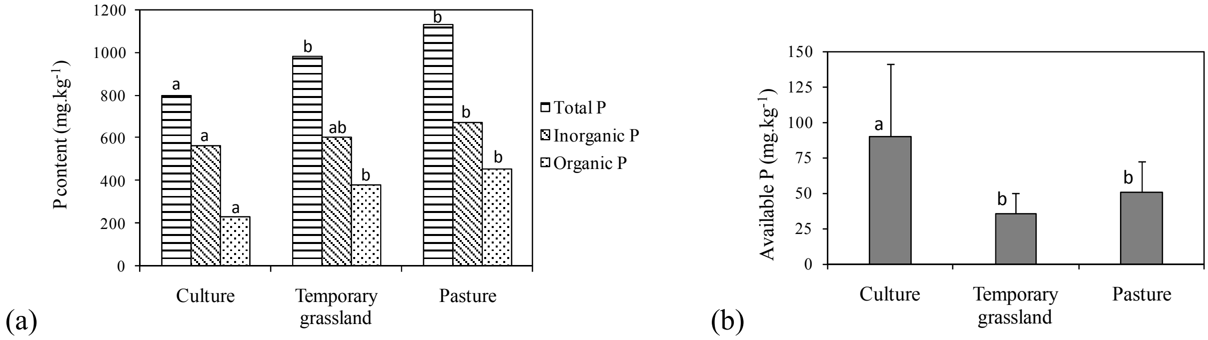

Figure 4. Effect of land uses on total, inorganic and organic P (a) and available P (b) for surface horizon.

Soil parameters influence

Soil properties had an important impact on P forms and P availability. Some parameters like total Fe or Al contents are considered as indicators of the quantities of adsorption sites for the phosphorus. Significant relationships were found with total P content. No correlation was found for clay or Ca contents.

Organic matter and pH were also related to P content. When levels of organic matter were high, so did P_{org} ($r=0.823^{***}$). However, levels of P_{av} were lower due to the P fixation on organic matter. For what concerns pH, the highest range coincided with highest P availability.

Conclusions

Parent material composition and land use are both responsible for differences in soil P contents. Parent materials influence the entire profile, while land use doesn't seem to influence deep horizons. Weathering is probably the most important process of P transformation in deep horizons. On average, P_{tot} in depth represented half of P in surface. Soils with the highest Al and Fe contents presented also the highest P_{tot} content but this P is not very available because of higher P sorption capacity. Some regions present higher environmental risks because of dominance of soils with low P sorption capacity and high P availability. This problem occurs in light textural soils under intensive agriculture. Indeed, crop soils have lower P contents than other soils but this P is highly available. So, the P management has to be thought according to the parental material and land use to avoid unsuitable effects for some regions.

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