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Mineralogical and physico-chemical properties of Ferralic Arenosols derived from unconsolidated Plio-Pleistocenic deposits in the coastal plains of Congo

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ABSTRACT

The main characteristics of soils under commercial *Eucalyptus* plantations on the Atlantic coast of the Congo were studied down to a depth of 5 m. The objectives were to investigate the mineralogical assemblage and distinguish between current versus old pedogenetic processes, and to find evidence of relations between minerals and cation retention in highly weathered sandy soil. These soils, developed from Plio-Pleistocene sandy deposits, were characterized by mineralogical uniformity over depth, with quartz contents ranging from 850 to 930 g kg^{-1}, a clay fraction dominated by kaolinite and a cation exchange capacity (CEC) < 0.5 $cmol_c$ kg^{-1} whatever the soil layer. Whilst dioctahedral vermiculite amounted to only 3% of the clay fraction, it played a key role in soil cation retention contributing to 49% of the mineral CEC. Vermiculitisation of muscovite was a current process showed by the changes in muscovite/vermiculite ratios with soil depth. The simple mineralogical assemblage of this soil made it possible to estimate CEC values for kaolinite ranging from 6.2 to 6.9 $cmol_c$ kg^{-1} for the 0–2 µm particle size. Their morphologies and saturation index of soil solutions showed that kaolinite had different possible origins: i) current precipitation from soil solution, ii) pseudomorphic transformation of pre-existing 2:1 phyllosilicates and iii) old particles present in the original deposit. Measured fine earth CEC below estimations summing together the contributions of all the mineralogical fractions showed that particle aggregation greatly influenced the cation retention capacity, even in these poorly structured soils.

Pedogenetic differentiations were weak in these soils because the elapsed time since deposition was too short to differentiate 'mineralogical horizons' from weathered materials. Our study showed that beyond the properties that minerals confer to soil, partially controlling the bioavailability of nutrients, their mineralogical and chemical characteristics infer current and former pedogenetic processes in this highly weathered tropical soil.

1. Introduction

Physical breakdown and chemical weathering of minerals are always intense under tropical climates, whatever the nature of the parent material (Churchman, 2000). Depending on their age, soils exhibit various stages of mineralogical weathering due to water-rock interactions. Element losses start with alkali and alkali-earth elements, followed by silicon, which results, at the end of the sequence, in the production of an assemblage of oxides and oxyhydroxides (He et al., 2008). Moreover, in geologically stable areas in the tropics, climate changes and geomorphic cycles may lead to polygenetic soils. Polygenesis involves new soil formation phases taking place on pre-weathered materials from previous phases (Muggler et al., 2007). In this context, large portions of the soil in the coastal plain near Pointe Noire in western Congo are derived from remobilized soils and saprolites partly deposited as slope deposits from the adjacent Mayombe Mountains (Cosson, 1955; Jamet and Rieffel, 1976). This detritic formation of continental origin dating from the Plio-Pleistocene (Jamet and Rieffel, 1976) supports deep Ferralic Arenosols (FAO, 1998). Their apparent chemical poorness makes them unsuitable for productive agricultural uses. The natural vegetation established on these soils consists of herbaceous savanna which has occupied this area since the Upper Holocene (Schwartz et al., 1995; Trouvé, 1992). Since 1978 42,000 ha of eucalypt hybrids have been planted in the area. Nutrient losses from this intensive forestry practice are compounded by the notoriously low CEC produced by chemical weathering that ultimately results in a relatively steady-state mineralogical–chemical state characterized by kaolinite and oxyhydroxides (Birkeland, 1999). Many studies have

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been undertaken in these eucalypt plantations on carbon cycles (D'Annunzio et al., 2008; Epron, et al., 2009; Marsden et al., 2008; Nouvellon et al., 2008), water and nutrients (Laclau et al., 2003a,b, 2005, 2010), root architecture and dynamics (Bouillet et al., 2002; Laclau et al., 2001; Marsden et al., 2008; Thongo M'Bou et al., 2008), and tree growth (Nouvellon et al., 2010; Safou-Matondo et al., 2005; Saint-André et al., 2005). However, little is known about the mineralogical and physico-chemical properties of the soil, which is a major constraint for comprehensive ecological studies and sustainable land uses. Moreover, different local studies, mainly gray literature (unpublished data and soil cartography) have shown that this type of soil is the one most frequently found in several countries of the Atlantic coast of central Africa from Gabon to Cabinda (Collinet, 1969; Delhumeau, 1969; Jamet and Rieffel, 1976). The objectives of this paper were to: i) assess the capacity of mineralogical studies to gain an insight into current and former pedogenetic processes in a tropical soil, and ii) accurately characterize soil chemical properties in a toposequence of highly weathered sandy soils largely represented in the coastal plains of central Africa that have remained largely unstudied.

2. Materials and methods

2.1. Study site

The *Eucalyptus* plantation extends from near the city of Pointe Noire on the Atlantic coast (Bas-Congo) of the Congo for about 90 km inland, at 4°S, 12°E (Fig. 1). The ecological situation has been described previously in Laclau et al. (2003a). In brief, the climate of the coastal plain is characterized by high atmospheric humidity (85% on average) with low seasonal variations (2%), and a mean annual rainfall of about 1200 mm with a marked dry season from May to October. The mean annual temperature is high (25 °C) with seasonal variations of about 5 °C. On the plateau, where most of the plantations are located, the altitude ranges from 80 to 120 m and the topography is slightly undulating. The bedrock is composed of thick detritic layers (down to 100 m) of continental origin and the soils are Ferralic Arenosols (FAO, 1998). The detritic sediments come from erosion of the adjacent Mayombe Mountains located 100 km to the East (Cosson, 1955; Jamet and Rieffel, 1976). These mountains are mainly composed of acidic rocks: granites, shales, quartzites and gneiss (Vellutini et al., 1988; Vicat and Gioan, 1989).

A pedological description was carried out in a catena of three soil profiles at the Kondi site (Fig. 1). Soils were sampled by genetic horizon for each profile. The first profile was representative of the plateau (P) at 88 m above sea level, which represents 90% of the planted area, the second was situated in a middle slope (MS) at 71 m above sea level, and the third in a lower slope (LS) at 59 m above sea level. The slope was regularly between the sampled soil profil. The toposequence was parallel to the slope and the P-MS and MS-LS sampled soil profiles were 389 and 438 m apart respectively.

2.2. Sampling and sample preparation

Approximately 1 kg of mineral soil was collected in a pit for each sample using a cylindrical corer down to a depth of 1 m. Soils were sampled between the depths of 1 m and 5 m using a screw auger. The soils were sieved to 2 mm to remove any roots and then stored to await analysis.

Fifty grams of each soil sample was first treated to remove organic matter using dilute H_2O_2 (5%), followed by Na saturation (NaCl, 0.4N) and dispersion with NaOH to prevent aggregate formation (Robert and Tessier, 1974). The clay and fine silt particles were separated by repeated sedimentation in a sedimentation cylinder. Following a predetermined settling time, the topmost suspension was removed according to Stockes' law (Robert and Tessier, 1974). The coarse silt (20–50 μm), fine sand (50–200 μm) and coarse sand (200–2000 μm) were subsequently isolated by wet sieving.

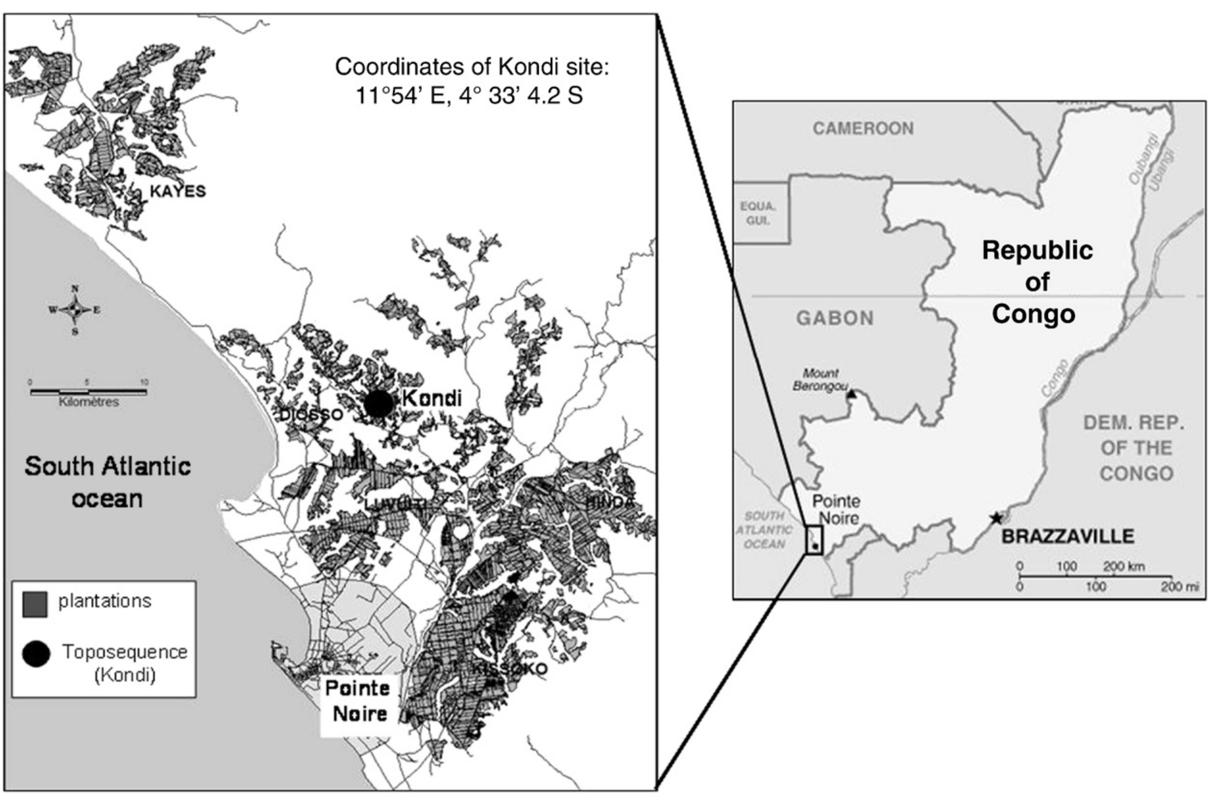

Fig. 1. Location of the Eucalyptus plantations and the soil toposequence (Kondi) near the Atlantic coast of the Congo.