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Effect of I- and S-type granite parent material mineralogy and geochemistry on soil fertility: A multivariate statistical and Gis-based approach

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A B S T R A C T

This study provides new insights into the effects of a parent material on inherent soil fertility. We describe the mineralogy and geochemistry of I- and S-type granites and their effect on soil fertility under similar environmental conditions in Borborema Province, NE Brazil, using standard mineralogical, geochemical and soil analyses as well as multivariate analysis and geographic information system approaches. We hypothesized that soils derived from I-type granites will develop higher natural fertility than those derived from S-type granites. The mineralogy and chemistry of the two different granitic parent materials have a profound effect on soil fertility. The S-type and I-type granites have different mineralogical compositions: the S-type granites have higher concentrations of silica, and the I-type granites contain larger concentrations of mafic and accessory minerals, mainly amphibole and apatite. Geophysical field measurements show different magnetic susceptibilities: for example, the I-type granites have substantial higher magnetic properties than the S-type granites. Soils derived from the I-type granites have higher natural fertility than soils derived from the S-type granites. Principal component, cluster and discriminant analyses (95% accuracy) were effective tools to discriminate among soils developed from different granites. Spatial distribution maps are suitable soil fertility management tools to guide and support soil fertility management decisions for improved soil- and crop-specific fertilization. These findings have wider implications in large parts of the tropics (South America, sub-Saharan Africa, India, SE and East Asia and Australia), which are underlain by igneous and metamorphic rock types, including S- and I-type granites, and where effective management tools are needed to increase the nutrient use efficiencies for increased productivity of food, fodder and energy crops.

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1. Introduction

The parent material is one of the five major factors that influence soil formation and is regarded as the initial state of a soil system (Jenny, 1941). The mineralogical and chemical nature of the parent material plays a major role in soil fertility (Van Straaten, 2007). Granitic rocks are abundant in the Earth's upper continental crust underlying large expanses of agricultural land in the tropics and in areas with temperate climates. In Pernambuco State alone, granites cover approximately 1/3 of the whole land area (Brazil, 2001). However, granites are generally regarded as nutrient-poor parent materials in the formation of soils; however, they differ widely in chemical and mineralogical compositions. Chappell and White (1974, 2001) simplified the classification of granites into I- and S-type granites. This classification, along with the use of A-type granites is widely used (Foden et al., 2015; Guan et al., 2014; Guani et al., 2013; Litvinovsky et al., 2015; Vilalva et al., 2016; Wang et al., 2014, 2015; Zhao et al., 2008).

In general, the S- and I-type granites are derived from the melting of meta-sedimentary sources and melt products of meta-igneous source rocks, respectively (Chappell and White, 1984; Chappell et al., 2012). The genesis and geochemical signature of I- and S-type granites have been widely studied (Almeida et al., 2007; Antunes et al., 2008, 2009; Chappell and White, 1974, 2001; Chappell et al., 2012; Clemens, 2003; Foden et al., 2015; Guan et al., 2014; Guani et al., 2013). Thus far, however, no attempts have been made to study the specific influence of the mineralogy and geochemistry of I- and S-type granites on soil fertility.

One of the most effective tools to study environmental and agricultural issues is the use of multivariate statistical techniques (Chen et al.,

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2008; Gielar et al., 2012; Templ et al., 2008). Principal component analysis (PCA) and cluster analysis (CA) have been used for multivariate analysis in soil science (Franco-Uria et al., 2009; Li et al., 2009; Silva et al., 2015) and have been mainly applied for source identification. The use of integrated methods such as multivariate statistical techniques and GIS approaches (Facchinelli et al., 2001; Li et al., 2004; Manta et al., 2002; Micó et al., 2006; Sun et al., 2013; Thuong et al., 2013; Varol, 2011) have rarely been used as tools to identify the natural soil fertility derived from different parent materials.

The objectives of this study were (i) to describe the petrology and mineralogy of I- and S-type granites of the Borborema Province, Pernambuco State, Northeast Brazil, and (ii) to address the effect of I- and S-type granites on soil fertility using geochemical and mineralogical methodologies supported by multivariate analyses as well as geographic information system (GIS) mapping techniques.

2. Material and methods

2.1. Site setting and sampling

This study was carried out in the Borborema Province, Pernambuco State, northeastern Brazil. Geologically, the Borborema Province is the western part of a major Late Neoproterozoic mobile belt (Brasiliano-Pan-African) that extends from Brazil into Africa in pre-drift reconstructions (Van Schmus et al., 2008). Petrographic and geochemical details of the Borborema Province can be found in a number of previous studies (Cruz et al., 2014; Da Silva Filho et al., 2014; Ferreira et al., 1998; Santos and Medeiros, 1999).

For this study, two geological granite zones were selected in eastern Pernambuco State (Fig. 1). The soil sampling along two transects (A and B) was carried out in areas with minimal anthropogenic disruption and similar climatic conditions. A total of 15 sites in each transect were selected, and the site intervals varied from 500 m to 1 km. Slight variations in these sampling distances were needed due to the absence of native vegetation or the presence of other rock types at the sampling site. Composite soil samples that consisted of three subsamples were taken from the sampling sites at depths of 0–20 and 20–40 cm.

The A-transect was characterized by soils derived from S-type granites and covered an area from 08°41′03.5″ to 08°39′56.4″S and 036°18′37.7″ to 036°05′49.3″W at an elevation between 609 and 764 m with gentle slope morphologies. The B-transect encompassed soils developed over I-type granites (08°42′15.7″ to 08°37′48.2″S and 036°01′33.0″ to 036°00′46.9″ N) at an elevation between 450 and 693 m with relatively steep slope morphologies. Soils are mainly Regosols (IUSS Working Group WRB, 2014). The climate, according to the Koppen classification, is semi-arid (BSh); it is characterized by an average air temperature of approximately 24 °C, and the annual rainfall ranges from 800 to 1000 mm. The study area is located on the Borborema Plateau (400–800 m). The vegetation is composed of semi-deciduous tropical forests and dry deciduous forests (Caatinga), a unique biome that is exclusively Brazilian and one of the most vulnerable sites threatened with desertification (Souza et al., 2012). The vegetation consists of thorny brushes that inhabit in arid and semi-arid regions of northeastern Brazil. This vegetation type occupies approximately 5/6 of the Pernambuco's surface area (Araújo Filho et al., 2000).

2.2. Granite analysis

The I- and S-type granites and their modal mineral compositions were determined from fresh rock samples, which were collected from each transect. The mineralogical analyses were made from thin sections. Optical microscopy was used to identify the minerals, and the point count method was employed to assess the proportion of each mineral phase. The thin section samples were prepared and analyzed at the Mineral Resources Research Company (CPRM/Brazil), Geological Survey of Brazil, in Recife, Pernambuco.

The major-element oxides (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, MnO, Na_2O, K_2O, and P_2O_5) of whole rock samples were determined using X-ray fluorescence (XRF) spectrometry (S8 Tiger model-1KW). Loss on ignition was determined at 1000 °C. The two granite types were also analyzed for their magnetic properties by scanning the samples with a handheld magnetic susceptibility meter (KT-10, Terraplus).

2.3. Soil analysis

The particle size distribution was obtained according to Gee and Or (2002), using Calgon as a chemical dispersant. All samples were subjected to a pre-treatment (H_2O_2) to eliminate the organic matter. The soil pH was measured in distilled water (1:2.5 soil:solution ratio). Potassium, Na, P, Co, Cu, Fe, Mn, Mo, Ni and Zn were extracted using the Mehlich-1 procedures (1:10 soil:solution ratio). Calcium, Mg and Al were extracted with 1 mol L^{-1} KCl (1:10 soil:solution ratio). All the elements were determined by optical emission spectrometry (ICP-OES/Optima 7000, Perkin Elmer). Then, the sum of the bases, cation exchange capacity and aluminum saturation percentage were calculated. The potential acidity ($H^+ + Al^{3+}$) was determined using the calcium acetate method (0.5 mol L^{-1}, pH 7.0), and the total organic carbon (TOC) was measured according to Yeomans and Bremmer (1988).

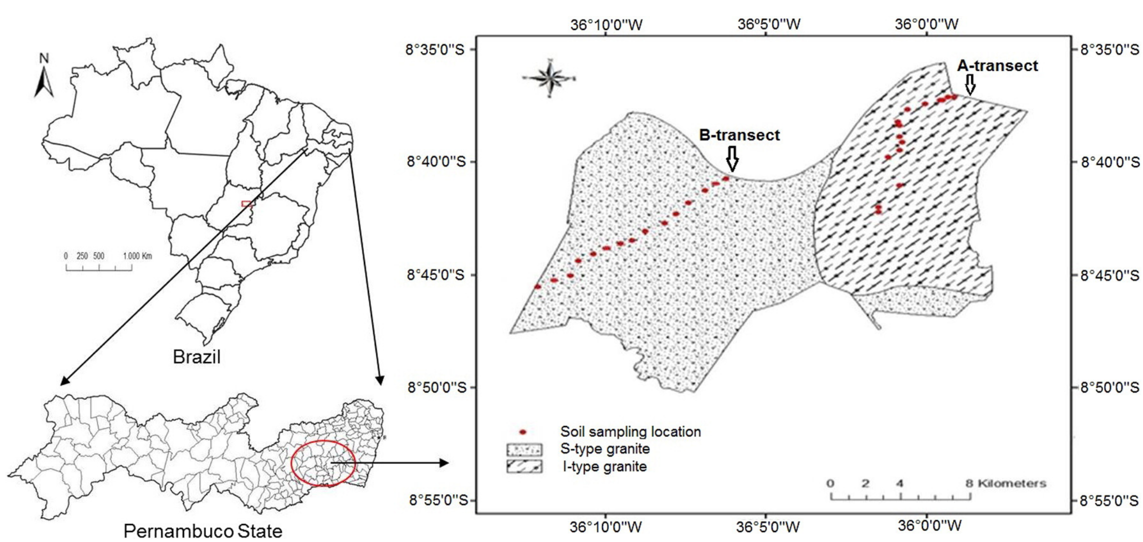

Fig. 1. Distribution of soil sampling location over I- and S-type granites from the Borborema Province, Pernambuco State, northeastern Brazil.

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