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Analysing the proximal gamma radiometry in contrasting Mediterranean landscapes: Towards a regional prediction of clay content

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ABSTRACT

The analysis of γ-radiometric data from proximal soil sensing measurements can be used to predict key soil properties for environmental and agricultural issues. These predictions require prior calibrations that use a large sampling of field data that could be significantly reduced if regional predictions can be established. However, such predictions may be challenging for Mediterranean regions because of the highly contrasted soils and specific geopedological characteristics (sedimentary rocks, low weathering, etc.). Our study focuses on the regional prediction of a key soil property (clay content), within highly contrasting geopedological groups (GPG) from the Languedoc region. The aims of the research were (i) to understand the relationship between γ-radiometric data and the clay content within the different complex GPGs and (ii) to predict the clay content from γ radiometry with a regional calibration based on the GPG as an auxiliary variable. A proximal soil survey using the γ radiometer, called "The Mole", was conducted in 8 areas of the Languedoc region. The plots were selected over different GPGs that are representative of the soil diversity and materials according to their weathering intensity and igneous components. In total, 242 sites were sampled based on a random grid cell for soil laboratory measurements. The soil texture and stoniness were analysed, and the particle size fractions were separated for mineral identification via X-ray diffraction. The activity of ^{232}Th [1 to 71 bq/kg] and ^{40}K [40 to 771 bq/kg] exhibits the largest range between the different GPGs, which spans the range of values measured in previous European studies. The relationship between the clay content and ^{232}Th is significant at a regional level [$R^2 = 0.60$; RMSE = 42 g/kg]. The residuals are significantly distributed according to the different GPGs. A new linear model based on the ^{232}Th activity and the GPGs improves the prediction of the clay content [$R^2 = 0.72$; RMSE = 35 g/kg]. Our study showed that ground γ radiometry can be used to predict the clay content within a complex Mediterranean sedimentary context. The ^{232}Th radionuclide is the best predictor. The disturbance of the relationship between the ^{232}Th and the clay content corresponds to the fine earth mineralogy type and the proportion of igneous pebbles.

1. Introduction

The implementation of sustainable agricultural, hydrological and environmental management requires an improved understanding of the spatial distribution of soils and soil properties on increasingly finer scales. Among other geophysical tools, gamma (γ) radiometry has been largely applied for estimating soil properties or delineating soil classes. On the regional scale, airborne γ radiometry has assisted in depicting the spatial patterns of soils and analysing pedogenesis processes (Martelet et al., 2013; Rawlins et al., 2007; Wilford, 2012). On the local scale, a large literature exists on the use of γ radiometry for estimating texture and clay content (Pikki et al., 2013; Priori et al., 2014; Taylor et al., 2010; Van der Klooster et al., 2011; Van Egmond et al., 2010), soil depth (Wong et al., 2009), potassium content (Pracilio et al., 2006), and cadmium contamination (Söderström and Ericksson, 2010).

Gamma radiometry is based on γ-ray measurements that record the activity of the naturally occurring long-lived radioactive isotopes of potassium (^{40}K), thorium (^{232}Th) and uranium (^{238}U). These isotopes produce γ-ray photons with a specific energy during their decay. Passive γ-ray soil sensors measure the energies of each radionuclide. These radionuclides are initially contained in igneous minerals. High contents of ^{232}Th and ^{238}U are found in micas and feldspars and are often present within specific minerals, such as zircon (Wedepohl, 1969). Even higher contents of the ^{40}K isotope are found in most micas and feldspars. These isotopes are also present in soils that have modified contents and that are influenced by the weathering intensity of the igneous rocks and by the redistribution of their minerals towards sedimentary rocks via erosion and sedimentation. Few studies have

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dissected the relationship between a radionuclide and the predicted soil property, which may identify perturbing effects that decrease the prediction performances.

In the absence of any comprehensive modelling of the complex relations between the above-evoked isotopes and the targeted soil properties, the estimation of soil properties from γ-ray spectra always requires prior calibration. The γ-ray spectra correspond to the classical energy spectra produced by the decay of radionuclides. Since the 1980s, it was been typical to record 256 channels of spectral data and to span an energy range of 0–3000 keV. However, in this conventional approach, the full spectrum was not utilised for analysis. Only specific energies of interest (windows) were analysed to estimate ^{40}K, ^{238}U and ^{232}Th (Minty and Hovgaard, 2002; Adamchuk and Viscarra Rossel, 2010) at the respective peaks of 1460, 1760 and 2615 keV. The energy levels in the selected windows contain information from other decay products as well, resulting in noisy results. Hendriks et al. (2001) attempted to overcome this problem by introducing the concept of Full Spectrum Analysis (FSA). The objective of his approach was to acquire quantitative reliable nuclide data in bq/kg. Viscarra Rossel et al. (2007) neglected the absolute values and produced a statistical analysis that directly compares the variance in spectra to the variance in soil property levels. Regardless of the calibration techniques, many data are required, which generates significant costs when γ-ray studies are applied separately to each of the typically surveyed plots.

The costs can be substantially reduced if a statistical function is calibrated at the regional scale and then applied to each plot that is included in the region. Priori et al. (2014) proposed statistical techniques for a regional calibration of soil textural and stoniness properties over a geologically variable vineyard (0.3 km^2). Loonstra (2010) found a regional relationship between ^{232}Th and the clay content that depends on the age of the parent material in 6 Northern European countries. Van der Klooster et al. (2011) compared the local calibration, regional calibration and global calibration of the relationship between ^{232}Th and the clay content. However, such regional calibration approaches are often limited by the intricacies of the different soils of the considered regions and the parent material with contrasting geochemical contexts that may impact the distribution of the measured isotope. This may significantly decrease the interest of a regional calibration compared to a local one (Van der Klooster et al., 2011).

This study focuses on the prediction of the clay content from γ-ray measurements within a Northern Mediterranean region that comprises highly contrasting soil and sedimentary parent materials. To address this complexity, the aim of the study was (i) to depict the relationship between γ-ray measurements and the clay content using detailed characterisations of the great geopedological groups (GPG) included in the region and ii) to test the use of GPG as an auxiliary variable for improving the regional calibration of clay content predictions from γ-radiometric data.

2. Materials and methods

2.1. Study area

The study area is composed of 8 vineyard plots located between Narbonne and Montpellier (in southern France) with a total area of 10 ha (the individual plots are between 0.5 and 3.5 ha). The plots were selected to include a variety of parent materials and soils representative of the Languedoc Mediterranean area (Fig. 1). These plots were studied in previous works with classical soil surveys, boreholes and geophysical transects (Coulouma et al., 2013).

The study area is characterised by a Mediterranean climate. The mean annual rainfall varies between 500 mm/y at the southern sites and 650 mm/y at the sites near Montpellier. The rainfall is irregularly distributed throughout the year, and the major periods of rainfall

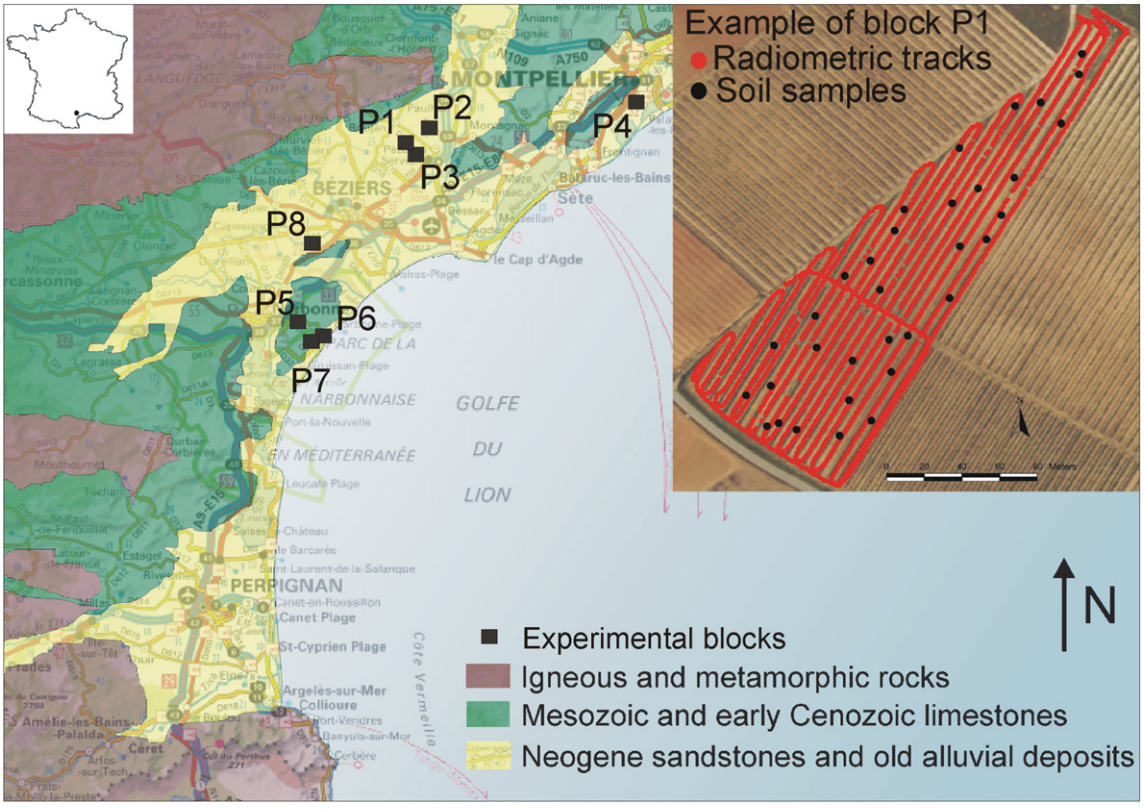

Fig. 1. The study area and the location of the vineyard plots with an example of γ radiometric track.