

# Impact of lignite on pedogenetic processes and microbial functions in Mediterranean soils



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## ABSTRACT

We compared a calcareous soil developed from a lignite vein (natural outcrop) and a control adjacent soil without lignite in order to assess the impact of lignite on pedogenetic processes and microbial functions in Mediterranean soils. Lignite was evidenced by the <sup>14</sup>C analysis, <sup>δ13</sup>C signature and SS <sup>13</sup>C CPMAS NMR spectroscopy in the various soil horizons. Physico-chemical (particle size analysis, pH, total organic carbon, carbonate content, nitrogen, sulfur, cation exchange capacity, crystalline and amorphous Fe and Al, mineralogy, bulk density) and biological (enzyme activities: β-glucosidase, arylsulfatase, acid phosphatase, arylamidase, fluorescein dilauryl hydrolase and fluorescein diacetate hydrolase; basal respiration and Biolog® catabolic profile) properties were also analyzed in all horizons. We showed that the naturally-occurring lignite modified soil organic matter quality and mineralogy and improved some soil properties such as clay content, C<sub>org</sub>, CEC and porosity. On the contrary, lignite had a higher C/N and higher recalcitrant C content compared to recent soil organic matter, which resulted in a decrease in the expression of microbial soil functions involved in the turn-over of the main bio-elements C, N, P and S due to lignite acting as a diluting factor (i.e. inert regarding microbial activities). The information derived from this study offers insight on the long term fate of lignite in soil, especially relevant if lignite is aimed at being used as amendment.

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## 1. Introduction

Mine overburden soils containing lignite have been studied extensively both for understanding their genesis and microbial functioning and for assessing the benefit of lignite addition to remediate degraded soils through improvement of their physical, chemical and biological soil characteristics (e.g. Rumpel et al., 1998, 2001, 2002; Rumpel et al., 2003; Rumpel and Kögel-Knabner, 2004; Frouz et al., 2011). First, coal-contaminated soils have been extensively studied (Karczewska et al., 1996; Pus, 2007) in terms of organic matter quantity and quality: airborne lignite-derived contamination or lignite inherent to the parent substrate and present in overburden soils around mining areas has been found to impact organic carbon amounts (Rumpel et al., 1998). In addition, lignite increased amounts of aliphatic and aromatic C species as compared to C derived from fresh plant material (Kwiatkowska

et al., 2008; Rumpel et al., 1998). In Southern Brazil the soil of a coal mining area contained up to 75% aromatic carbon originating from lignite (Dick et al., 2006). In the Lusatian lignite mining district (Germany), lignite-rich soils were enriched in carboxyl-C, phenolic-C and aromatic-C while the amounts of O-alkyl-C and alkyl-C groups were decreased (Fettweis et al., 2005; Rumpel et al., 2002).

Lignite in anthropogenic soils has also been found to impact pH, mineralogical composition (Ogala et al., 2012) and microbial communities (Rumpel and Kögel-Knabner, 2004). As reviewed by Fakoussa and Hofrichter (1999), in laboratory experiments lignite was found to be degraded and depolymerized by several microbial mechanisms. For example, lignite could be attacked by microbial enzymes (e.g. peroxidases and esterases) especially, but not exclusively (Maka et al., 1989), those of the white-rot fungi involved in lignin degradation of plant litter. Thus, lignite degradation was not driven by specific mechanisms, which implied that lignite alone could not induce enzyme synthesis. As a consequence of these microbial processes, lignite was found to be mineralized, humified and incorporated into the soil microbial biomass of young (14 to 37-year-old) rehabilitated mine soils. Thus,

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according to Rumpel and Kögel-Knabner (2002), during the early stage of pedogenesis, lignite can aid the formation of mine soil. However, its importance as microbial substrate decreases with increasing age and development of the soil, due to the progressive enrichment in more labile OM derived from plant litter (Rumpel and Kögel-Knabner, 2002, 2004; Rumpel et al., 2001). To our knowledge older mine soils (>40 yrs) or soils with naturally-occurring lignite have been poorly or not at all investigated for their physico-chemical as well as their microbial properties (e.g. soil enzymes, respiration and functional diversity), while the latter serve several important functions in soils: they are intimately involved in the cycling of nutrients, affect fertilizer use efficiency, reflect the microbiological activity in soil and thus may act as indicators of soil changes due to lignite enrichment (Preston et al., 2001).

While reference studies to natural systems with lignite are scarce, they would help shading light on the long term fate and effects of this material in soil. One reason may be the restricted occurrence of such soils because lignite outcrops are limited in extension, have been scraped by early mining practice or destroyed by forest fires. In Provence (South-East of France) however, two types of lignite-enriched soils can be found: (i) soil of mine tailings and (ii) soils developed on natural lignite outcrops, which can still be found in the environment where the edges of the coal veins are reaching the surface.

We chose to compare two forested calcareous soils differing only in lignite content as assessed by morphological description and verified by subsequent NMR analysis,  $\delta^{13}\text{C}$  and  $^{14}\text{C}$  measurements. Minerals associated with lignite were identified and the related changes in physico-chemical soil characteristics were investigated. The effect of lignite on biogeochemical nutrient cycles was also assessed by the measurement of basal respiration and functional catabolism as well as various enzymatic activities (FDase, FDLase, arylsulfatase, arylamidase,  $\beta$ -glucosidase and acid phosphatase).

This study aims at a better understanding of the long-term effect of lignite on physico-chemical and microbiological soil characteristics

and at foreseeing the evolution of coal-contaminated soils in view of an improved management of mine tailings. Moreover, studies on reclaimed soils from lignite mine have dealt mostly with low pH environments associated with acid mine drainage while lignite in naturally alkaline soils has been poorly investigated with few exceptions (Dixon and Schulze, 2002).

## 2. Materials and methods

### 2.1. Site description and sampling

Two soil profiles were sampled along a road-trench at a distance of 20 m from each other. The studied site, thereafter named Kirbon, is sketched in Fig. 1. It is located 45 km North-East of Marseille (43°25.602'N/005°39.754'E) in a typical Mediterranean forest with holm oaks (*Quercus ilex*, *Quercus alba*) and pines (*Pinus halepensis*), on a northeast-facing slope. Both soils are Rendosols (Baize and Girard, 2008) or Rendzic Leptosols (WRB, 2006). Two parallel lignite layers, 5- and 15-cm-thick respectively, separated by a ca. 5-cm-thick limestone layer, progressively reach the surface with a 15° angle. The lignite-rich profile (referred to as (+)) is developed where the first lignite layer reaches the surface. It comprises three horizons: IIA, IIIA/IIC and IIIC. The IIA horizon is developed into the first lignite layer while the IIIA/IIC horizon corresponds to the limestone layer and the IIIC to the second lignite layer. The profile without lignite (referred to as (–)) comprises A, A/IIC, IIC and IIIC horizons. Both C horizons result from the weathering of the underlying lower Campanian (Valdo-Fuvelian) limestone, which is interposed by lignite. Both lignite veins were sampled between the described profiles at 1.5 m below ground level (resp. named outcrop or OCL1 and OCL2 in Fig. 1) but only OCL2 (simplified as OCL) was analyzed together with the soil horizons, while both layers were analyzed for radiocarbon. An unweathered lignite sample (courtesy of Patrick Schaeffer, Strasbourg University), thereafter named ML, sampled at depth (mine lignite) in the same

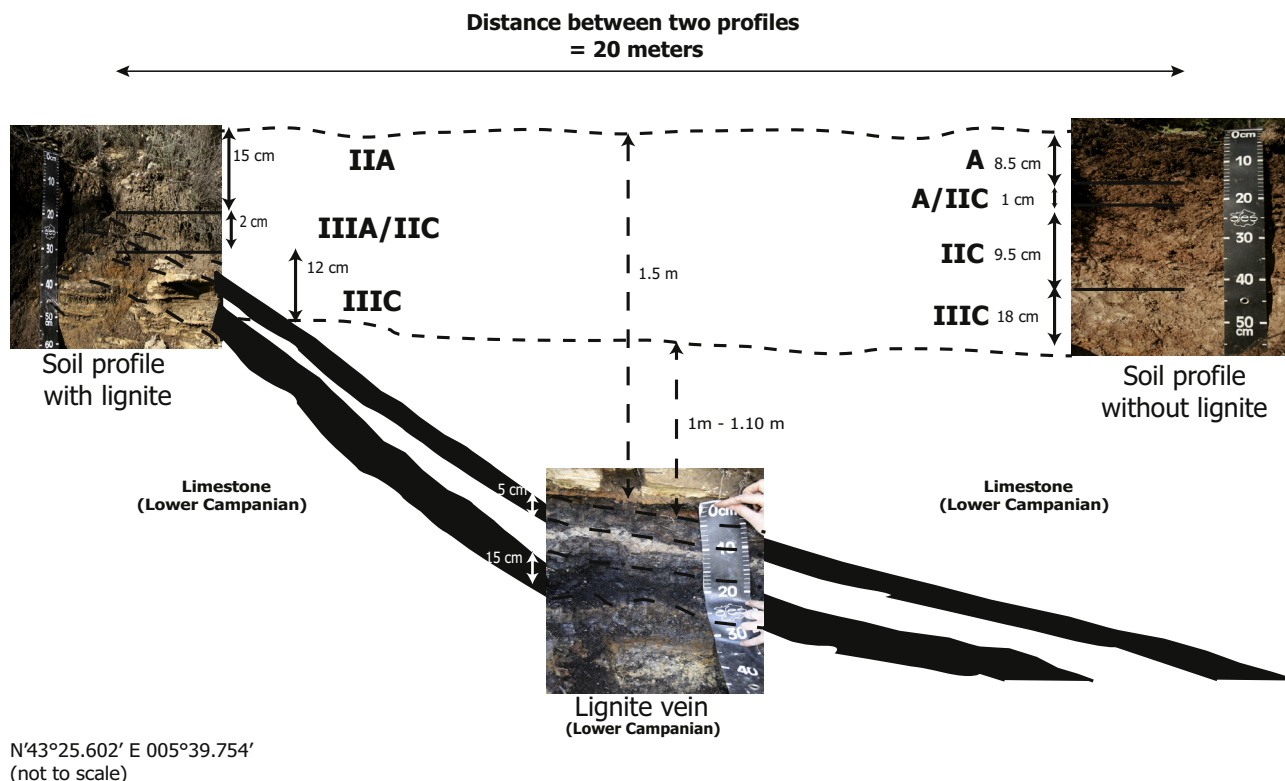


Fig. 1. Scheme of the Kirbon site: two soil profiles without and with lignite originating from a lignite outcrop and the lignite vein (OCL).

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