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Changes in the pathway and the intensity of albic material genesis: Role of agricultural practices

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ABSTRACT

Albic material is a widespread soil diagnostic material. The genesis of albic materials is known to be very sensitive to changes in environmental conditions resulting from natural or anthropic driving forces. Common agricultural practices like liming or drainage improvement are able to change the nature or the intensity of albic material genesis. The direction and the amplitude of such changes have however remained controversial because of a lack of quantitative approaches. In this paper, the intensity of the genesis of albic material was quantified in one forested Retisol and compared to those previously quantified in two limed and cropped soils sampled respectively far from and close to a drain line. Liming practices were found to decrease the intensity of the genesis of albic material by two thirds with reference to natural soil evolution under forest. Contrastingly, artificial drainage improvement initiated the development of physically-driven albic material genesis due to translocation of soil particles but without significant implication of any reduction process. The observed increase in the intensity of albic material genesis after artificial improvement was higher in the immediate vicinity of drains than was its decrease after liming applications. It was however the reverse for the rest of the soil between the drains. As a result, the overall effect of cultivation was a slowdown of the genesis of albic horizons by comparison to the natural evolution under forest. Such changes in both the nature and the intensity of albic material genesis clearly demonstrated that i) numerous genetic pathways may be simultaneously or successively active at a particular location, and ii) anthropic driving-forces like agricultural practices may be a way to favour one particular genetic pathway at the expense of another.

1. Introduction

Human activities have been acknowledged for many decades as key drivers of soil evolution (Jenny, 1941; Bidwell and Hole, 1965; Yaalon and Yaron, 1966). Numerous agricultural practices like fertilisation, tillage, lime and organic matter amendments, irrigation or artificial drainage have been designed and are widely used to control various chemical, physical or biological soil properties. In most cases, however, the cumulative impact of such agricultural practices on soil change at the decadal to centennial time scale remains largely unknown, and tends to be ignored as a result. A better understanding of the anthropogenic impact on soil evolution at the decadal to centennial time scale represents one key frontier in pedology, and is needed to support the science and management of the environment, ecosystems and global change (Richter and Markewitz, 2001; Richter, 2007).

In the search towards a more thorough understanding of anthropogenesis, albic material constitutes an ideal test case for a number of reasons. The genesis of albic material, that leads to the removal of clay and free iron oxides, leaving behind an uncoated and light-coloured soil material — also called soil morphological degradation (Lozet and Mathieu, 2002) — is frequently observed in many soils. Albic horizons are indeed encountered in seven of the twelve orders in soil taxonomy (Bockheim, 2016), and “albic” is used as a principal qualifier in 10 soil groups in the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014). Despite considerable research dealing with the characterisation of the exact mechanisms involved in the genesis of albic material, the incidence and relative intensity of the different genetic pathways are still under question (Bockheim and Hartemink, 2013). Besides podsolization (Pédro et al., 1978; Bockheim, 2012), the genesis of albic material is related alternatively to the dispersion and eluviation of clay minerals associated with iron oxides (Driessen et al., 2001; Montagne et al., 2008, 2013; Szymanski et al., 2011; Nikorych et al., 2014; Bockheim, 2016), to the dispersion and eluviation of clay minerals after reduction and removal of iron oxides bonding clay particles (Jamagne, 1978; Pédro et al., 1978; Payton, 1993; Van Ranst and De Coninck, 2002; Boivin et al., 2004; Weisenborn and Schaetzl, 2005), or finally, to the ferrolysis process (Brinkman, 1970, 1977, 1979) involving the destruction of clay

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mineral lattices as a result of repetitive cycles of reduction and oxidation. Last but not least, the genesis of albic material was found to be particularly sensitive to anthropic-driven changes in environmental conditions. Albic materials or horizons are commonly associated with forest vegetation, suggesting a strong dependency on land-use (Bockheim, 2012, 2016). In that respect, the qualitative assessments of Langhor (2001) and Cornu et al. (2007), comparing forested and cultivated Retisols (IUSS Working Group WRB, 2014) — also called Albaqualf in the Soil Taxonomy (1999) — suggested that liming slowed down the development of albic materials. By contrast, studying a sequence of cultivated Retisols, Montagne et al. (2008, 2013) observed an increasing development of albic material in Retisols after the installation of an artificial drainage network. The overall impact of cultivation, seen as a combination of various practices able to have competing impact on the development of albic material, remains however unclear due to a lack of quantification of the development of albic material under natural forest vegetation and therefore of a quantitative balance between the slowing down and the accelerating of the development of albic material by some of the different agricultural practices.

We propose here to quantify the development of albic material in one forested Retisol considered as a reference for a development of albic material as natural as possible. The development of albic material under forest was then compared with those in two limed and cropped Retisols sampled respectively far from and close to a drain line (already studied by Montagne et al. (2008, 2013)). Results are finally interpreted in the light of previous work (Cornu et al., 2007, 2012a,b; Montagne et al., 2008, 2009, 2013) to conclude on the impact of cultivation and of artificial agricultural drainage on i) the mechanism and ii) the stage of the development of albic material with reference to that newly quantified in one forested Retisol.

2. Material and methods

2.1. Sites and soils

The soils considered in this research are classified as Retisols (IUSS Working Group WRB, 2014), previously referred to as Albeluvisol in the 2006 World Reference Base for Soil Resources (IUSS Working Group WRB, 2006), and also called Albaqualf in the Soil Taxonomy (1999). Forested and cultivated Retisol plots, separated by less than a hundred metres and developed in the same Quaternary loam of aeolian origin, were selected on the Yonne plateau in the south-eastern part of the Parisian Basin, France. Historical records indicate that neither the forested nor the cultivated plots experienced any change in land-use for at least the past two centuries (Cadastre, 1828). The cultivated plot was limed and amended with organic matter. Although liming was not very widespread, it was practised in the study area since at least the beginning of the 19th century (Clout and Phillips, 1972). The selected cultivated plot was thus hypothesised to have been limed for the last 200 years. At last, an artificial drainage network consisting in plastic perforated pipes spaced 15 m apart was buried at 1-m depth perpendicularly to the main slope by subsoiling in 1988, i.e., 16 years before sampling.

The soils showed the classical A-E-Bt profile of Retisols with albeluvic glossae penetrating into the finer-textured Bt-horizon (Fig. 1). The forested soil showed from the surface to 5–10 cm-depth, a silty A-horizon with a sub-angular blocky structure and a yellowish-brown colour (moist Munsell colour of 10YR 5/4). From 5 to 10 to 30–40 cm-depth, the silty E-horizon, depleted in clay and in iron oxides, was light-coloured (moist Munsell colour of 10YR 8/2) and showed a sub-angular blocky to massive structure. The lowest part of the E-horizon was characterised by numerous Fe and Mn segregations ranging from diffuse impregnations to concretions with sharp boundaries. Underneath the E-horizon, one could observe albeluvic glossae, consisting in a complex juxtaposition of albic material of a silt loam texture interfingering into prismatic clods of a silty clay loam texture characteristic of a Bt-horizon. From 30 to 40 cm-depth to 50–60 cm-depth, albic materials with a white-grey (moist Munsell colour of 10YR 8/1) to pale-brown (moist Munsell colour of 10YR 7/4) colour were dominant. This horizon is hereafter labelled as E&Bt-horizon. Contrastingly, from 50 to 60 cm-depth to 1 m-depth, the clayey prismatic clods of yellowish-brown colour (moist Munsell colour of 10YR 5/6 to 10YR 5/8), called ochre, became more abundant than the lighter coloured parts. This horizon is called glossic Bt-horizon from 50 to 60 cm in depth and Bt-horizon beneath. Black concretions and impregnations occurred in the core of the ochre prismatic clods both in the E&Bt-horizon and in the glossic Bt-horizon.

In the cultivated plot, the E-horizon has been partially blended into the ploughed Ap-horizon whereas the rest of the profile showed a horizonation similar to that observed in the forested plot (Fig. 1). From 0.5 to 2 m from the drain line, the E&Bt- and the glossic Bt-horizon showed more abundant albic material, black concretions, and impregnations, whereas no change was recorded beyond 2 m from the drain (Montagne et al., 2008, 2013).

2.2. Soil sampling strategy and analytical procedures

Three soil profiles were sampled: one in the forested plot, and two in the cultivated plot, respectively 60 cm and 400 cm from the drain line (Fig. 1). The latter soil profile was far enough from the drain line to be considered as largely unaffected by artificial soil drainage (Montagne et al., 2008, 2013). The impact of cultivation — including vegetation change, ploughing and liming — was quantified by comparing the cultivated soil sampled at 400 cm from the drain line to the forested soil whereas the impact of artificial drainage was quantified as in

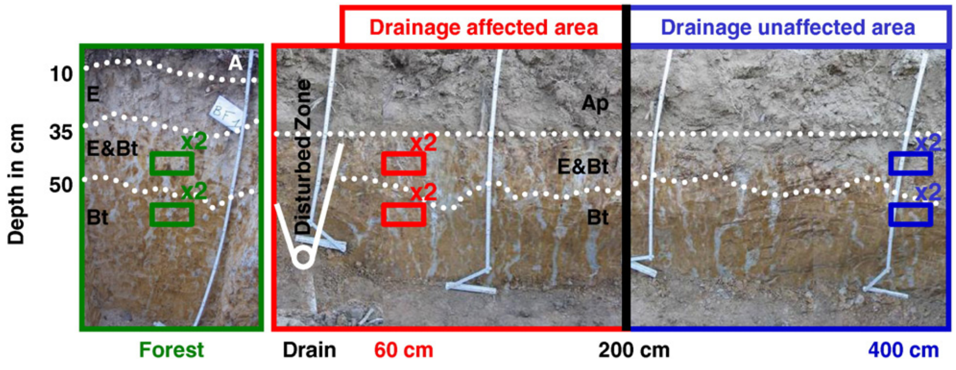

Fig. 1. The forested pit and the cultivated trench showing the soil horizonation and the sampling zone for soil monoliths in the E&Bt and glossic Bt-horizons (boxes). For scale reasons, the glossic and the non-glossic parts of the Bt-horizons were not distinguished. On the cultivated trench, the zone disturbed by subsoiling and the drainage affected and unaffected areas are also shown.