Quaternary International 346 (2014) 28–40

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

1500 years of soil use reconstructed from the chemical properties of a terraced soil sequence

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A R T I C L E I N F O

Article history:
Available online 18 April 2014

Keywords:
Land use
Agrarian landscape
Terraces
Soil properties

A B S T R A C T

Colluvial soils can store signals of the environmental conditions occurred during their formation, including the anthropogenic activities they supported. Their study may provide important information for reconstructing and interpreting the evolution of cultural landscapes. We studied the chemical properties of a terraced soil system located in the town of Santiago de Compostela (NW Spain). Aluminum, Fe and Si fractionation was studied by selective dissolution techniques with high vertical resolution, combined with elemental composition and other soil properties such as phosphate retention (P_{ret}) and NaF pH, aiming to identify modifications produced by land use changes and agricultural management practices since Antiquity. The buried epipedon of the paleosol, which is considered to exemplify the pre-terracing soil, showed strong andic character. We argue that its attenuation in the anthropogenic soil layers is, firstly, a consequence of the decreasing amounts of reactive components (organic matter, organo-Al complexes and low ordered aluminosilicates) due to a dilution by mixing superficial and sub-superficial horizons. Secondly, the introduction of agricultural techniques led to modifications in the chemical stability of organo-metal complexes influencing the accumulation of organic matter. Other signals, such as variations in soil acidity, and P and Ca contents, point to management practices as fertilization or liming. The increasing amounts of Fe inorganic compounds in the more recent layers indicate a strong weathering and degradation, probably as a consequence of the intensification of the agricultural use. Our results indicated continued and progressively more intensive agricultural use during the last 15 centuries, linked to the development of the town.

1. Introduction

The Galician (NW Spain) rural landscape may be defined as a so-called *concave landscape* (Ballesteros-Arias et al., 2011), which is based on the complementarity of the farmland and the hillsides to address to three key issues: i) to provide pastureland for the livestock, ii) the use of crop rotation systems and iii) the production of gorse (*Ulex europeus* L.) that could be used as a fertilizer, as previously pointed out by Bouhier (1979). Even it is widely accepted that the present rural landscape is largely inherited from earlier agricultural transformations (Criado-Boado, 1989; Martínez Cortizas et al., 2000, 2005), only a few studies have been undertaken to relate ancient agricultural activities to the formation of the present-day landscape in Galicia (Bouhier, 1979; Criado-Boado, 1989; López-Sáez et al., 2003; Ballesteros-Arias et al., 2006a, 2010; Carrión et al., 2010). In this area, ancient agricultural stages are supposed to have comprised the exploitation of shrubs, such as gorse (*Ulex europaeus* L.), which was either growing wild or sown (Bouhier, 1979), slash and burn agriculture, or first tillage practices. Initial forms of fertilization and the availability of a more complex technology are assumed to have allowed the inception of progressively more intensive

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http://dx.doi.org/10.1016/j.quaint.2014.03.023
1040-6182/

agricultural cultivation. Intensive farming may have involved the use of methods to correct the acidity and the loss of fertility by means of the use of organic and inorganic amendments. Topographical modifications became evident including the correction of the slopes by building artificial horizontal surfaces, i.e. terraces, which facilitate ploughing and improve productivity (Ballesteros-Arias et al., 2006a). Previous research has demonstrated that terracing was used by human groups to control soil erosion at least since the mid-Bronze Age (Martínez-Cortizas et al., 2009). Parcero-Oubiña (2006) and López-Sáez et al. (2009) documented agrarian terraced structures in Iron Ages sites. Later, a profound anthropization of the rural environment took place in Early Middle Ages (Ballesteros-Arias, 2010) involving the generalization of the construction of terraces in Galicia.

There is archaeological and historical evidence of a Roman settlement in the area of Santiago de Compostela from the 4th century AD. It has been traditionally considered that the area was abandoned after the Roman Period due to the lack of information and remains for the following period, except for a necropolis from late Antiquity. However, some authors hypothesize the continuity of a considerably large settlement and a dynamic rural society between 400 and 800 AD (Caamaño and Suárez, 2003), which would have required increasing agricultural productivity for subsistence. A process of expansion of the lands devoted to agriculture started by the 6th century AD (Ballesteros-Arias et al., 2006a, 2010). This expansion is thought to mark the onset of a deep transformation of the agricultural landscape, involving new features and techniques that favored the intensification of the agricultural activity, including the construction of terraces. Unfortunately, there is a lack of bibliographic sources about these changes, as the existing documentation dates from the 9th century or later, when Santiago started to be an economic and trade centre nourished by the *inventio* and the creation of the Apostol Santiago basilica. Moreover, their study does not tell much about land uses and technologies that were involved in the transformation of the agricultural landscape, as they were mostly related to overall crop yields.

Under these circumstances of lack of historical sources and/or archaeological remains, the signals stored in environmental archives would be crucial to provide information on landscape transformations during the early expansion of the town. The imprints of land use changes remain accessible in the form of signals that can be extracted and interpreted to get information on the kind and intensity of the activity that took place. In particular, colluvial soils are capable of storing information of changes that occurred during sediment deposition and the subsequent soil formation (Kalis et al., 2003; Leopold and Völkell, 2007). Among the factors conditioning the development of colluvial soils, anthropogenic processes have a relevant role. The anthropic impacts may be direct, modifying the morphology or properties of the superficial formations, or indirect by altering the magnitude and/or direction of the effect of other factors of soil formation (mineralogical composition, geochemical weathering system, the contributions from other compartments, organic matter microbial decay, and others). As stated by Leopold and Völkell (2007), Holocene colluvial soils are closely related to human activity. These authors define them as colluvial sediments accumulated due to anthropogenically induced processes (by forest clearance, grazing, agriculture or mining). In NW Spain, the typical colluvial soil is formed by a succession of A horizons and characterized by high contents of organic matter and organo-metallic compounds (especially organic matter-Al). Several studies have demonstrated the suitability of this type of soil as paleoenvironmental archives to reconstruct, for example, erosion phases, vegetation changes and fire history in NW Spain (Martínez-Cortizas et al., 2009; Kaal et al., 2011, 2013). Taking advantage of this potential, we analyzed one polycyclic soil sequence in the terraced system of Monte Gaiás (Santiago de Compostela, NW Spain), located a few hundred meters E-SE of the town, apparently in one of the first domesticated territories in the area. Because they are human-made, terraced soils are not standard colluvial soils. Nonetheless, their formation process is equivalent, involving successive deposition of soil material that result in a sequence of A horizons above the original, in situ, edaphic cycle (paleosol).

Research on ancient agricultural terraces in NW Spain is scarce. Ballesteros Arias (2003, 2010) and Ballesteros Arias et al. (2006a,b) have studied the construction and chronology of Medieval agricultural spaces in Galicia, and Ferro-Vázquez et al. (2013) have published some data on the modification of the edaphic properties in terraced soils of Santiago de Compostela. More abundant research was carried out on lands historically devoted to agriculture in other Spanish locations, addressing diverse archaeological objectives (Quirós Castillo et al., 2014; references therein; Puy and Balbo, 2013).

Soils of Monte Gaiás develop on amphibolitic colluvial material. When combined with a humid environment, basic and metabasic rock materials (gabbros, amphibolites, basic granulites), which are rich in weatherable minerals (Macías et al., 1978; García Paz et al., 1986; García-Rodeja et al., 1987), naturally generate soils with relevant amounts of highly reactive components, such as poorly crystalline mineral constituents and organo-metal complexes (Macías et al., 1978; García Paz et al., 1986; García-Rodeja et al., 1987). This pedogenetic process is known as andosolization, and leads to soils with andic properties (IUSS-WRB, 2007): low bulk density, high water retention potential, low permanent charge, an exchange complex dominated by variable charge surfaces, and high anion retention capacity (as for example of phosphates). A highly stable soil organic matter (SOM), due to the predominance of stable organoaluminic complexes and the adsorption of organic compounds on low-ordered minerals (Boudot et al., 1989; Zech et al., 1997), also contributes to the andic character. This type of SOM is usually abundant in the surface horizons of andic soils (Martin and Haider, 1986; Aran et al., 2001).

However, this pedogenetic trend can be modified by anthropogenic impacts (Fernández- Sanjurjo, 1994; Parffit et al., 1997; Verde et al., 2005), to the point that the classification of soils with andic properties subjected to anthropogenic transformations is still a matter of discussion (Tejedor et al., 2009). There is a wide array of research focusing on modifications of the soil properties due to agricultural use or as a result of terracing in Spain. This addresses pedogenetic, degradation and recuperation issues (González-Prieto et al., 1996; Ruecker et al., 1998; Martínez-Casasnovas and Sánchez-Bosch, 2000; Dunjó et al., 2003; Pardini et al., 2003; Ramos et al., 2007; Zornoza et al., 2009). For soils with andic properties, most of the research has been carried out on those developed on volcanic materials (see e.g. Hernández-Moreno et al., 2007; Neris et al., 2012 and references therein) and only few in non-volcanic andic soils (Macías et al., 1978; Camps-Arbestain and Macías, 2000; Barreal et al., 2001; Camps-Arbestain et al., 2001; Verde et al., 2005, 2010). The change from forest to agricultural use and/or a different soil management has been shown to attenuate the expression of andic properties (Parffit et al., 1997; Verde et al., 2005).

Although there is evidence of deep landscape modifications in NW Spain as early as 6000 BP (Martínez-Cortizas et al., 2009) it is thought that Pre-roman anthropogenic impacts on the soil had a local character and frequently were without major pedogenetic effects (Van Mourik, 1986; Guitián Rivera, 2001; Muñoz Sobrino et al., 1997; Martínez-Cortizas et al., 2009). In this phase, fire-involved clearances were the main tool for land management