Soil development indices in a soil chronosequence formed on Lower Pleistocene terraces in the north-western Duero basin (León, Spain)

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Abstract
A study was carried out in a soil chronosequence developed on alluvial deposits, comprising six terraces displaying marked variations due to altitudinal differences. Many of their morphological properties, such as their original red colour, have become obscured beneath a variety of colours as a result of the intense hydromorphism acting upon the impermeable Miocene clay substrate which underlies these formations. The accumulation indices (AI) for total clay and fine clay, and most especially those corresponding to the iron oxides (Fed/Fet), were found to be good indicators, highlighting developmental and evolutionary differences between the six soils.

Key Words
Terraces, chronosequence, clay, iron oxides, accumulation indices

Introduction
The majority of soil properties change according to the length of time other formation factors are active. Nevertheless, due to the high number of edaphic properties, it is difficult to assess a soil's development stage from a single property. Thus, many authors have established indices based on comparing variations in the properties of a given soil with corresponding variations in the soil's parental materials. To this end, some researchers have concentrated primarily on morphological properties (Bilzi and Ciolkosz, 1977; Harden, 1982), whilst others have used analytical laboratory data (Walker and Green, 1976; Birkeland, 1984; Levine and Ciolkosz, 1983; Harrison *et al*., 1990). Soil sequences spread over a system of river terraces comprise the most frequently studied type of chronosequence.
The aims of the present work were to assess the changes in some properties over time and establish the relative age of the edaphic formations corresponding to the six levels of river terraces spread over the soil chronosequence of the mid-upper reaches of the Orbigo River (NW Duero basin, León, Spain).

Methods
Over geological time this river has left a typical scaled relief, with abundant horizontal surfaces placed between sharp scarps. A representative profile was chosen from each of the six geomorphological surfaces distinguished. The fluvial deposits have thicknesses ranging between 4 and 5 m and are composed mainly of gravels, cobbles and stones and sand originating from the erosion of quartzites and slates.
The study area is characterised by a mean annual temperature of 10.4º C, mean annual rainfall of 521 mm and mean annual ETP of 645 mm. Soil temperature and moisture regimes are mesic and xeric, respectively. The sequum comprises an A horizon (normally umbric), and an AB transition horizon followed by a thick argillic horizon (Bt). Due to the intense hydromorphism acting upon the underlying Miocene clay substrate, this latter horizon generally displayed high colouring with fading of the original red, presenting intensive migration of iron and manganese. According to the WRB classification (FAO, 2006), the six soils comprised Umbric Acrisols, corresponding to Typic Palexerults according to the Soil Taxonomy (USDA, 1999).
In order to carry out the characterisation proposed as the aim of the study, three accumulation indices (AI) were estimated: the accumulation index of total clay, the corresponding accumulation index of fine clay and the accumulation index associated with intensity of mineral alteration, represented by the accumulation of iron oxides (Fed/Fet). Total iron (Fet) was determined using the method proposed by Pratt (1965), whilst free iron oxides (Fed) were extracted using the method developed by Merha and Jackson (1960).

Results
The six soils studied in the river chronosequence comprised old evolved edaphic formations of a marked superacid nature as shown by the mean pH values in KCl of 3.5 – 3.7, base satutation percentages of 20-30% and Al saturation of 50-75%. The gravels and quartzite blocks corresponding to the three upper terrace levels presented intensive desintegration. Height between the highest terrace T6 and the following terrace T5 was 23 m; between T5 and T4, 19 m; between T4 and T3, 51 m; between T3 and T2, 36 m, and between T2 and T1, 35 m. In total, a height of 164 m was recorded between the upper and lower terraces.

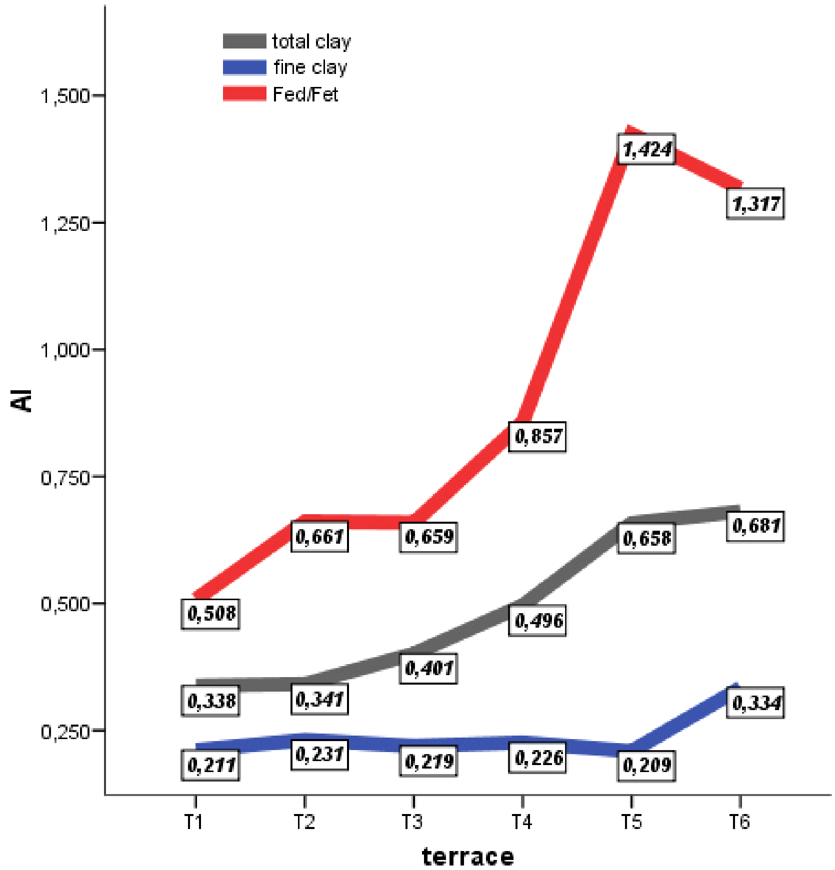

Figure 1. Accumulation Indices (AI) of total clay, fine clay and Fed/Fet.

The AI corresponding to total and fine clay respectively were estimated from differences between clay content (%) in the Bt horizons and the A and AB horizons; this difference was divided by the sum of Bt horizon thicknesses (cm).The AI of free iron oxides (Fed/Fet) was calculated in the same way.
The evolutionary and developmental level of the six soils comprising the chronosequence can be seen in Figure 1, where the AI obtained for each terrace is given. The total clay AI were highest on levels T6 and T5, whilst T4 and T3 presented medium values and lowest and very similar values were recorded for T2 and T1. However, the fine clay AI did not present such clear differences, and variations in the AI corresponding to the Fed/Fet ratio were found to be a much better indicator of the development of this soil chronosequence. For a given intensity of weathering, the free Fe content (Fed) should increase in proportion to total Fe content (Fet). On this basis, T6 and T5 presented greater development and mineral alteration than the lower terraces T4, T3, T2 and T1.

Conclusion

In the soil chronosequence studied, comprising highly evolved soils with thick argillic horizons where the hydromorphism hinders the expression of significant morphological features. The accumulation indices (AI) corresponding to total clay content and proportion of crystallized iron Fed/Fet were found to be excellent indicators of degree of edaphic evolution and development. These indices enable evolutionary differences to be established and the relative age of these edaphic formations to be determined.

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