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Soil organic carbon evolution after land abandonment along a precipitation gradient in southern Spain

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ABSTRACT

Land abandonment is the dominant form of land use change in the Mediterranean over the last decades, and determines the soil organic carbon (SOC) evolution during the secondary succession following abandonment. However, the rate of succession strongly depends on climatic conditions and the extent to which these determine the SOC dynamics is largely unknown. The aim of this study is determining these dynamics along a precipitation gradient (1085-650-350 mm yr^{-1}) on noncalcareous rocks in southern Spain. Fields abandoned in different periods, as verified on aerial photographs taken in 1956, 1977, 1984, 1998, 2001, 2004 and 2009, were selected using a chronosequence approach. SOC was determined using a spectrometer, vegetation was described, and NDVI calculated from Landsat images. SOC and NDVI evolution were analysed subsequently. In the two wettest sites SOC increased after land abandonment until it approached a plateau. Mean accumulation rates were 0.11 kg C m^{-2} y^{-1} for the wettest and 0.06 kg C m^{-2} y^{-1} for the intermediate site. These sites reached the long-term state, similar to the stocks in (semi) natural fields, in c.a. 10 years (wettest) and c.a. 35 years (intermediate). SOC and NDVI followed parallel trends, so SOC stocks were mainly driven by inputs from vegetation. At the dry end of the gradient, where NDVI's (<0.1) were very low, the SOC stocks did not respond to changes in NDVI for the 50 year period.

1. Introduction.

Soils contain approximately 1500 Pg of organic carbon, twice the amount of carbon stored in the atmosphere and roughly three times the C stored in terrestrial vegetation (Raich and Potter, 1995; Lal, 2004). The amount of C stored in a soil is the result of the balance between inputs and outputs. Inputs are determined by vegetation cover, since they are mainly plant-derived residues deposited aboveground as well as belowground. Outputs are C losses resulting from mineralization, leaching of dissolved organic C and erosion (La Mantia et al., 2013). The critical role of vegetation determining changes in soil organic carbon (SOC) stocks upon land use change (LUC) has been widely reported (Post and Kwon, 2000; Guo and Gifford, 2002; Poeplau et al., 2011). Nearly all studies compare SOC stocks before and after LUC. The conversion of natural vegetation to cropland indeed meets the characteristics of a drastic change, but in the case of cropland abandonment, a secondary succession occurs with colonization by grasses in the first stage and woody plants in later stages. Some studies have addressed SOC changes along secondary successions (Knops and Tillman, 2000; Rhoades et al., 2000; Zhang et al., 2007; La Mantia et al., 2013; Novara et al., 2013). In general, a net SOC stock gain after cropland abandonment is reported due to an increase in the input of organic matter, above as well belowground, and an increase in resistance to decomposition of the litter produced (Guo and Gifford, 2002). The estimated time to recovery of the original SOC stock ranges from 5–7 years in the Dominican Republic (Templer et al., 2005), to 230 years in a sandy plain of Minnesota (Knops and Tillman, 2000). SOC dynamics differ according to the previous land use i.e., cropland or grassland (Post and Kwon, 2000; Guo and Gifford, 2002; Templer et al., 2005). In particular, there is no agreement on the response of SOC after forest establishment on grasslands. Some studies have reported SOC increments (Hibbard et al., 2001; McCulley et al., 2004), whereas the opposite has also been documented (Guo and Gifford, 2002). Alberti et al. (2011) mentioned that precipitation is the key factor determining the type of response after conversion of grassland to forest, indicating a threshold around 900 mm, above which a net decrease could be expected. According to Poeplau et al. (2011), there is an initial decrease of SOC followed by an increment, resulting in a final net

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SOC gain. Precipitation is often mentioned as one of the main factors affecting SOC changes after LUC (Guo and Gifford, 2002; Jackson et al., 2002; Alberti et al., 2011; Poeplau et al., 2011). The balance between net primary production and decomposition is the net biome production that determines SOC sequestration or depletion (Ciais et al., 2010). On the one hand, precipitation affects the net primary production, and thus the organic matter inputs to the soil (Guzman and Al-Kaisi, 2010). This is even more evident in semiarid environments, where water is the limiting factor. On the other hand, precipitation affects soil moisture, one of the main factors modulating the decomposition rate of organic matter in soil, together with soil temperature (Powlson et al., 2007).

During the last decades, abandonment of agricultural lands has been one of the most important processes in rural areas in many parts of Western Europe, especially in the Mediterranean region (Nunes et al., 2010). Between 1961 and 2011, 24.5% of the acreage under annual and permanent crops in southern Europe has been abandoned (127,450 km^2) and 17.0% (35,200 km^2) in Spain (FAO, 2013). This phenomenon has been attributed to a complex of socio-economic factors such as globalization as well as specific policies of the European Union and the local governments that reduced the subsidies for extensive farming. This resulted in an abandonment of rainfed agriculture in the uplands and encouraged the development of irrigated agriculture and tourism along the coast (Onate and Peco, 2005; Lesschen et al., 2008). While secondary succession in temperate regions usually leads to the development of a forest., the final stage in Mediterranean environments depends on the availability of water. Grasses and shrubs mostly dominate the later stages of the succession in semiarid lands (Bonet, 2004). Climate affects the species composition of plant communities along a secondary succession and consequently is a key factor in SOC dynamic after land abandonment.

The precipitation gradient in southern Spain covers an area with similar mean annual temperature extending from the strait of Gibraltar (mean annual precipitation (MAP) >1100 mm) to Cape of Gata (MAP <200 mm). Within this gradient, changes have been detected in the runoff generation mechanisms, in the role of soil surface components determining hydrological response, in the water use by vegetation and in the vegetation patterns by comparing areas with the same lithology (Ruiz-Sinoga et al., 2010a,b; Ruiz-Sinoga et al., 2011a,b). The aim of this study is to quantify the effect of climate on SOC stock dynamics after land abandonment. We studied sites along the gradient described above to quantify SOC evolution after land abandonment on each site, related SOC evolution to precipitation and temperature and determined the role of vegetation influencing SOC evolution.

2. Material and methods

2.1. Study sites

The study was carried out in southern Spain along an East-to-West precipitation gradient (Fig. 1). The gradient ranges from the strait of Gibraltar, with precipitation of more than 1100 mm y^{-1}, to the Cape of Gata with less than 200 mm y^{-1} (Ruiz-Sinoga et al., 2010a). Four study sites were selected: Gaucín (GAU), Almogía (ALM) and two sites near Gérgal (GER; Fig. 1 and Table 1). These specific sites were selected because: (i) in spite of the differences in annual precipitation, the regime was similar; (ii) all the sites are located in the same biogeographical province, which ensures similarities in the secondary succession; (iii) the land use history is similar and (iv) the sites are all on noncalcareous metamorphic micaschists. The decisive factor determining the site selection was the different precipitation, which is the most important variable affecting SOC in the mid latitudes at the continental to regional scale (Adler et al., 2003; Minasny et al., 2013). Unfortunately, all abandoned fields on micaschists in GAU and ALM were originally almond and olive groves. As land use history explains a large part of the total SOC variability (Schulp and Veldkamp, 2008), we preferred to restrict the study to abandoned cereal fields for all

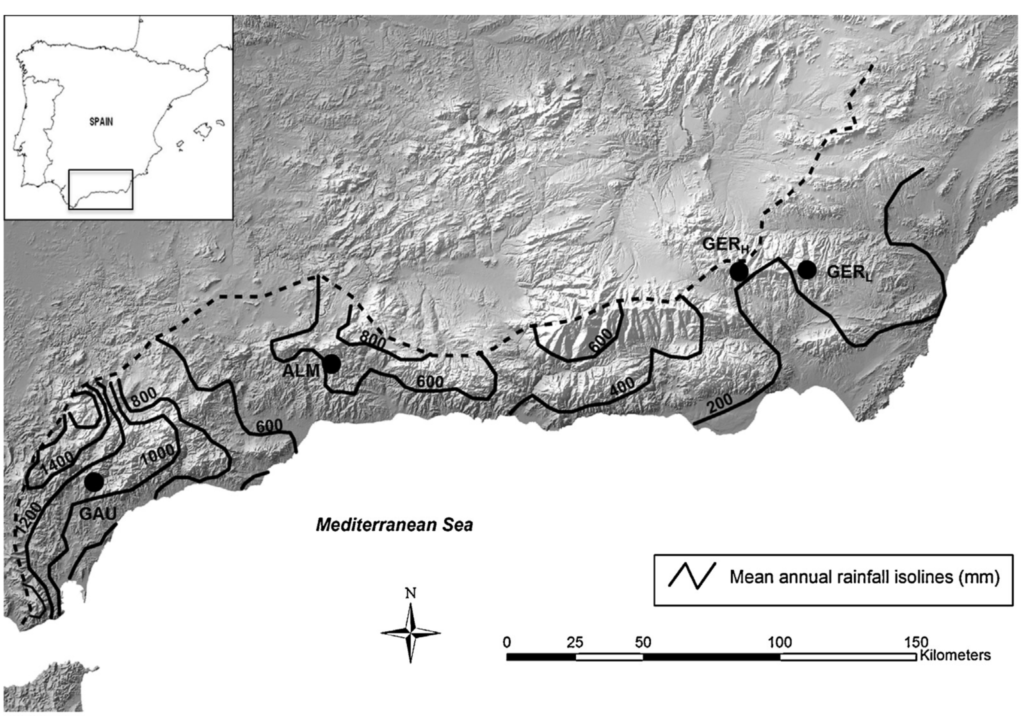

Fig. 1. Precipitation gradient and localization of the study sites.