Atmospheric dust additions as a soil formation factor

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ABSTRACT

The Mediterranean area is distinguished by at least four features that determine the nature of its soils. These are its climate, its mountains, the addition of exogenous dust and ongoing anthropogenic effects.

We here present three cases in which the influence of atmospheric dust additions can be detected in the soils of representative circum-Saharan contexts – the Canary Islands, Betic intramontane depressions, and the Sierra Bermeja peridotite massif (Málaga).

The unique position of the Canary Islands determines important rates of dust deposit, largely depending on position on the relief. The nature of the dust contrasts with the rocky substratum of the islands, and the marine and volcanic context can also affect the nature of the deposits.

The numerous, extensive intramontane basins of the Betic Cordilleras act as large captors of atmospheric dust, with rates similar to those found in the Canary archipelago. The carbonate content of these exogenous additions represents a significant component that should be taken into account when establishing the carbonate accumulation regime in these soils.

Sierra Bermeja is a rather different case. It constitutes the first abrupt relief in the area of the Strait of Gibraltar which, together with the prevailing winds, leads to anomalous concentrations of silica and carbonates in the upper horizons of its soils, unlike the ultrabasic nature of its substratum. Here, the texture and composition of supplies suggest an origin in the Campo de Gibraltar, rather than in the desert. Instances of contamination have recently been confirmed as having this origin.

Key words: Dust deposition rates, forming-factors, semiarid areas, aeolian additions.

INTRODUCTION

Like water, wind must be considered a geodynamic agent with the double role of being an erosive agent in some places, while in others it is a formation factor, supplying material that is incorporated into soils. McLeod (1979), Simonson (1995), and Yaalon (1997), among others, have underlined the importance of wind in soil genesis, but the process needs much more attention in semiarid areas.

The latter aspect is significant in circum-Saharan areas, because the Sahara desert releases about 80 to 120 Tg year^{-1} (1 Tg=10^{12} gr) to Europe (Swap et al., 1996). Loÿe-Pilot and Martin (1996) found rates of about 12.5 t km^{-2} year^{-1} in the western Mediterranean. Specifically, Díaz-Hernández and Miranda (1997) established rates in the southern Iberian Peninsula of about 23 t km^{-2} year^{-1}, with 8.5 t km^{-2} year^{-1} due exclusively to the Saharan influence, which represents 36% of the total during 21% of the year. The aim of this paper is to detect the presence of these additions and their range of values, to determine the evolution of aeolian carbonates in the soil profile and to describe the role of dust additions from less distant origins.

THREE EXAMPLES IN A SEMIARID CONTEXT

1. Dust deposition rates on the Canary archipelago

Grand Canary Island is located in the eastern Atlantic, and, due to its proximity to the Sahara Desert, is regularly affected by Saharan dust. When haze conditions occur, the particulate/aerosol accumulation rate was found to be slightly higher (5.4±3.8 mg m^{-2} h^{-1}) than under non-haze conditions (4.3±2.1 mg m^{-2} h^{-1}). These values were obtained from a year's weekly sampling at several plots in NE Grand Canary located at different altitudes and distances from the coast (Menéndez et al., 2007). Mean values of dust accumulation decreased with increasing altitude (from 79 to 17 g m^{-2} yr^{-1}, in an altitudinal range of 10 to 945 m a.s.l.). The rates obtained would imply very thick soils, which do not correspond with the soil status of the archipelago, where erosion and deep translocation of material must be taken into account.

XRD analysis of airborne dust found quartz, carbonates, feldspars, magnetite, aragonite, halite, and minor amounts of illite, kaolinite-chlorite and palygorskite. Quartz is considered allochthonous because it is not present in the volcanic substrate of the island. However, the quartz concentration in haze conditions was only 10% higher than in non-haze conditions. This mineralogy suggests an external source, but does not preclude a recycled origin.

Although the volcanic substrate of the sampling plots often consists of clinopyroxenes, olivine, amphibole, feldspars and zeolites, among others, the studied aeolian dust samples either did not contain these minerals at all, or in some cases only in minimal amounts. This could be due to the comparatively large grain sizes (phenocryst and microcryst up to 0.06 mm) and low fragmentation, or transformation through weathering in other minerals. It could also be due to the prominence of external airborne dust that reduces the proportion of these minerals below the detection limit of the analytical techniques employed.

2. Carbonate accumulation by aeolian additions to soils of Betic depressions

In this context, Díaz-Hernández and Miranda (1997) determined the dust deposition rate to be 23.06 g m^{-2} yr^{-1}. On the basis of data by Menéndez et al. (2006) and Díaz-Hernández and Párraga (2008), the carbonate input in soils of the area has been estimated at as much as 10 g m^{-2} yr^{-1}. To determine the effect of these additions on soils, a model simulation was carried out considering the soil as a 10 cm sided cell column 4 m deep. Water is the vector that transfers carbonates from one cell to another as long as there is drainable water in some of them, and considering the porosity of each (damping phase). The next cycle would be desiccation by evapotranspiration, which extracts the water without going beyond the permanent wilting point (PWP) limit, causing a concentration of the soil solution and eventual precipitation of salts if the solubility product is raised.

The simulation of aeolian carbonate addition was carried out in completely decarbonated parent material, with 15% field capacity, 6% PWP and 1.5 g/cc bulk density. Arid and xeric regimes were simulated for a period of 1 kyr (results in Fig. 1). In Fig. 1A (case of aridic regime), carbonate concentration occurs at two levels: in the top soil the carbonate increases from 0 to 6-7 % to 25 cm depth, with a maximum of approximately 2% at 1 kyr; this carbonate accumulation disappears below 150 cm depth. In the case of xeric climate (Fig. 1B), maximum carbonate accumulation occurs at about 100 cm depth, and there is important carbonate accumulation in deep levels down to 400 cm. The patterns of carbonate accumulation in both climate regimes are very different.

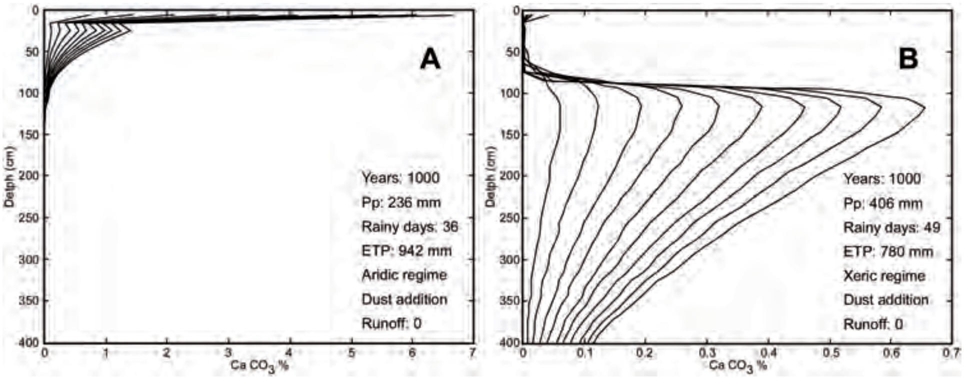

Figure 1: Temporal evolution of carbonates, translocated in soils with arid (A) and xeric (B) regime and only dust additions.

3. Compositional aspects of soils in Sierra Bermeja (Málaga)

The case of the ultrabasic massif of Sierra Bermeja is somewhat different. Soil studies have shown clear differences in composition between leeward slopes populated by the endemic *Abies pinsapo* and the rest of the area occupied by *Pinus pinaster*.

Chemical analyses show low contents in Ca (Fig. 2A, 305-1323 g kg^{-1}, n=5) and K (52-105 g kg^{-1}, n=5), typical of ultrabasic soils in the *Pinus pinaster* area. However, on the lee slopes, levels of Ca and K were much higher (1393-2282 g kg^{-1} and 126-224 g kg^{-1} respectively), high enough to support endemic *Abies pinsapo*, elsewhere only growing on limestone.

Granulometric studies (Fig. 2B) show a strong increase in fine sand (50-200 μm) in the upper horizons of these lee slopes (media = 14.8 %, stdev = 6.3 %, n = 5) which could not be found for lee soils (media = -0.6 %, stdev = 3.3 %, n = 5). This grain size indicates a transport distance up to 100 km (Yaalon, 1987; Dong et al., 2003), corresponding to the "Campo de Gibraltar" area southwest (main wind direction) from Sierra Bermeja mountains.

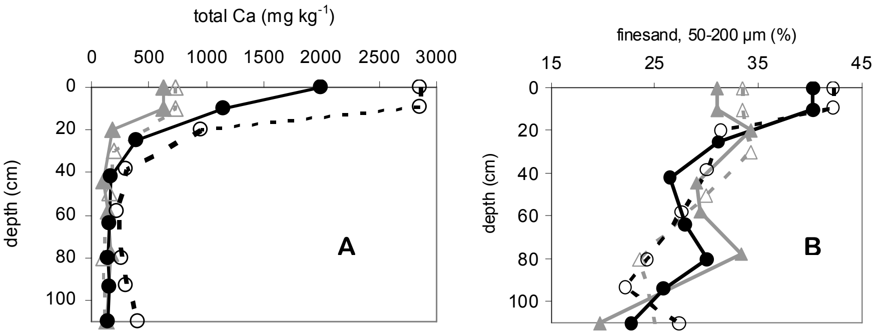

Figure 2: Depth-wise (y-axes) variation of total Ca (A) and finesand (B) in typical profiles from

Much of this area is formed by flysch with marl and sandstone components rich in K and Ca (Stromberg and Bluck, 1998; Gibbons and Moreno, 2002) and the Aljibe flysch, one of the main geological units of the Campo de Gibraltar region, is especially rich in quartz arenites (Stromberg and Bluck, 1998) which could be the origin of the quartz grains found by Yusta et al. (1985), who detected a presence of quartz (8-16 %) in the fine sand fraction of samples from the study area, something that is often ascribed to aeolian additions. As quartz is not present in ultrabasic rocks, which are the only minerals found in Sierra Bermeja, the only possible origin is aeolian. Unlike the other two examples, the local wind regime here is clearly predominant over Saharan winds, thus minimizing dust supply from this source.

CONCLUSIONS

The cases studied demonstrate the presence of exogenous additions and their importance for soil genesis in circum-Saharan areas. These dust additions can have proximate and distant origins and can be high enough to greatly exceed the thicknesses observed in these soils. The two further mechanisms of erosion and translocation collaborate in harmonizing these results.

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