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Radioisotopic and physicochemical background indicators to assess soil degradation affecting olive orchards in southern Spain

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ABSTRACT

Soil degradation is a major agrienvironmental issue under Mediterranean climatic conditions. To assess soil erosion magnitude under orchard plantation, soils in an undisturbed area – located within an archaeological protected site in southern Spain – were analysed to establish its physicochemical status, the initial ^{137}Cs fallout and the natural level of radioactivity taking into account the content of naturally occurring radionuclides (NOR). The vertical profiles of NOR mass activities confirmed its non-disturbance. 90% of the ^{137}Cs content was concentrated in the top 20 cm and the physicochemical parameters confirmed as well the undisturbed status of the site. The base-line level of ^{137}Cs was established at 1925 ± 250 Bq m^{-2} with a coefficient of variation of 23% and an allowable error of 11%. This ^{137}Cs background was used to assess soil erosion magnitude in a close orchard field using the ^{137}Cs method. The maximum erosion rates reached 19 t^{-1} ha^{-1} yr^{-1} and a sediment delivery ratio of 29% was evaluated, both values confirming an unsustainable soil loss magnitude due to the combination of water and tillage erosion processes since the 1950s. The radium equivalent activity and the absorbed dose rate results highlighted a difference between eroded and deposition sectors in the cultivated field confirming that these parameters could be used to some extend to assess pedologic processes.

1. Introduction

European countries of the Mediterranean basin are threatened by soil degradation, especially by soil erosion which can reach an ultimate stage leading to desertification (Bennett, 1960; Boardman and Poesen, 2006; Cerdà et al., 2010; Zdruli et al., 2010). The Global Assessment of Human Induced Soil Degradation (GLASOD) survey carried out during the 1980s by the United Nations Environment Programme (UNEP) and the International Soil Reference and Information Centre (ISRIC) established that over 40% of the Spanish territory is characterised by severe to very severe human induced land degradation (FAO, 2005). Agricultural areas in southern Spanish regions are particularly affected due to inappropriate land management coupled with specific agriclimatic and geomorphological conditions (steep slopes, shallow soils, semi-arid Mediterranean climate) that accelerate erosion and desertification processes. Cultivated lands under olive cropping have been pinpointed by several investigations (e.g. Gómez et al., 2009a,b,c,d, 2003) to be particularly erosion-prone, because of the high proportion of bare soil in conventionally tilled olive orchards and their location on steep slopes. For these reasons, soil degradation by water erosion is recognized as a major threat to sustainability of olive cultivation in southern Spain (Gómez and Giráldez, 2009). However, there is presently no available data on historical rates of soil erosion that has sufficient temporal resolution. Therefore to overcome this limitation and lack of information, the authors proposed an innovative investigation that involves the use of fallout radionuclides (FRN) and naturally occurring radionuclides (NOR).

The measurement of natural background radiation and anthropogenic radionuclides in terrestrial environments – especially in soils – has been carried out in many countries for several decades to establish base line data of radiation levels (Lee et al., 2009). It was also used, in northern Spain, under mountainous Mediterranean climate with continental influences, to complement information on the different factors that can affect their lateral and depth distributions mobility within ecosystems (Navas et al., 2011). The natural radioactivity in soils depends on the nature of the substratum and

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can be used as baseline information to detect and quantitatively determine possible man-made contamination (War et al., 2008). In nature, the greatest portion of the external irradiation comes from terrestrial radionuclides and especially from NOR (i.e. ^{40}K, ^{226}Ra and ^{232}Th). The agricultural impact on NOR soil content can be potentially used as an indicator of anthropogenic impact and disturbance in agriecosystems (Boukhenfouf and Boucenna, 2011; Buccianti et al., 2009). In Spain, except for the studies of areas affected by uranium mining and milling (e.g. Blanco et al., 2005; Vera Tomé et al., 2002), or studies in mountainous forested area (e.g. Navas et al., 2002) sometimes coupled with long-lived artificial radionuclides investigation (e.g. Vaca et al., 2001), there is little investigation on NOR in areas devoted to agricultural activities, or if so, it is mostly related to phosphogypsum application for soil reclamation (e.g. Abril et al., 2009).

The use of NOR as an indicator of anthropogenic impact on agriecosystems is still in its infancy. Since the mid-1990s several studies have been conducted using anthropogenic radioisotope (i.e. ^{137}Cs) to highlight and quantify the intense dynamics of erosive/sedimentary processes in the northern part of Spain, especially in the central Spanish Pyrenees (e.g. Gaspar et al., 2012; Navas and Walling, 1992; Navas et al., 2005, 2007; Soto and Navas, 2004; Quine et al., 1994) and to a limited extent in the northeastern part of Mallorca Island (Estrany et al., 2010). However, based on available literature (e.g. Schoorl et al., 2004a,b), FRN investigations in southern Spain, especially on orchard fields, are very limited.

FRN, especially ^{137}Cs as soil tracer, have been used worldwide at various scales to assess medium and short term soil erosion and deposition processes (Mabit et al., 2008a; Zupanc and Mabit, 2010). The accuracy of the information provided by this method is mainly based on a key parameter that is the ^{137}Cs reference inventory value to be established in an undisturbed site. The careful selection and the precise determination of its baseline ^{137}Cs areal activity is a major necessary investigation prior to the use of ^{137}Cs data to investigate soil movements in agricultural fields (Mabit et al., 2008a).

The overall assumption of our study is that the use of radionuclides (FRN and NOR) could provide a "toolbox" to validate the predictions of historical erosion rates in olive orchards in mountainous areas in southern Spain. Following a similar protocol applied by the authors in Slovenia (Mabit et al., 2010), the objectives of this preliminary study were: (i) to establish the soil radiometric background (NOR and ^{137}Cs) and the physicochemical information in an undisturbed area for evaluating soil degradation and soil quality in neighbouring cultivated orchard fields, (ii) to establish a precise reference inventory value of ^{137}Cs fallout, and (iii) using the ^{137}Cs method, to assess the magnitude of soil erosion in a typical Spanish orchard field located a few meters from the investigated undisturbed area.

2. Material and methods

2.1. Description of the study area and soil samples collection

The municipality of Montefrío is located in the south-western part of the Iberian Peninsula (Fig. 1). The region extension is around 220 km^2, of which 81% are cultivated, mostly under olive trees. Only 5% of the area is devoted to forest or grazing land. It is a mountainous area, with elevation ranging between 800 m a.s.l at the village (37° 19′ 19.66″ N, 4° 0′ 19.17″ W) and 1600 m a.s.l at the highest point (Sierra de Parapanda). Most of the non-cultivated land is located on the top and steepest sides of the mountains running across the municipality. The climate in the area of Montefrío is continental Mediterranean with an average annual precipitation of 630 mm, a mean annual evapotranspiration of 750 mm, and a yearly average temperature of 15.2 °C. From available documents and results from farmer and land owner inquiries, an undisturbed site ("Peña de los Gitanos") having experienced neither significant net erosion nor deposition was selected as a reference site (Fig. 1). This site is less than 500 m from one of the orchards and within 10 km of the orchard area studied by Vanwalleghem et al. (2011).

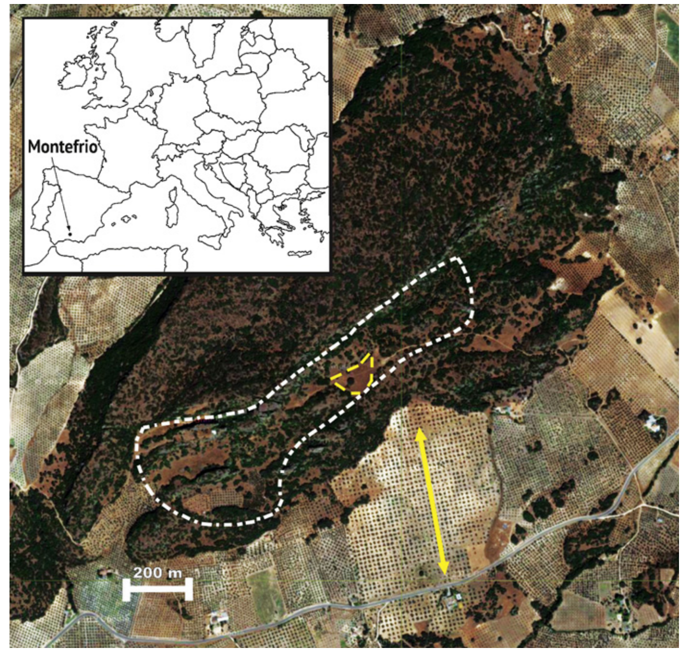

Fig. 1. Location map of the study area in the Granada province/Southern Spain. The protected archaeological site is delimited by the white lines, with sampled area indicated in yellow; the transect investigated in the olive field is represented by a yellow arrow. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Excavations of the archaeological site "Peña de los Gitanos" have found evidence of human presence 2000 years BC, with remains from Iberians, Romans and Muslims. Archaeological campaigns have been performed at the site since the early XXth century. Due to its historical value, strict restriction of agricultural activities has been respected during the XXth century, the site being only occasionally grazed by farm animals. The area is covered by open Mediterranean forest with the dominant trees being holm oak (*Quercus ilex*), gall oak (*Quercus faginea*) interspersed with shrubs, mostly llentiscle (*Pistacia lentiscus*), terebinth (*Pistacia terebinthus*) and annual grasses. The site is located on limestone material (calcarenites).

The status of this protected area guarantees that no anthropogenic activities took place. Combined with its flat topography, and proximity to the orchards where the studies on historical erosion have been developed, this area has the potential to allow the establishment of NOR original content and ^{137}Cs deposit, as well as providing information on the original fertility of undisturbed soils in the area.

The investigated site was a small ellipsoidal surface of 1.5 ha (centre coordinates 414,759.35; 4,132,618.08 m) located at 1020 m a.s.l with a small inclination (slope steepness <1%) in the southwest direction. Sampling points were located on two perpendicular transects, spaced by an average distance of 6 m (Fig. 2). Using a hand-operated corer and following the methodology of Deckers et al. (2004), a total of 13 micropits were sampled per 5 cm increments until bedrock was reached (i.e. 0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm and when possible, 20–25 cm, 25–30 cm, 30–35 cm, 35–40 cm, 40–45 cm, 45–50 cm, 50–55 cm and 55–60 cm). Actually, at several sampling points shallow soil development