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Can *terra rossa* become water repellent by burning? A laboratory approach

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ABSTRACT

Fire usually induces water repellency (WR) in soils. Reduction in infiltration rates, increase of runoff and erosion are some of the consequences of WR in fire-affected soils. Most forest soils can develop WR by burning; however some previous observations in burned terra rossa soils have shown little changes in WR. Laboratory controlled experiments have been done with samples of terra rossa from 14 different sites. The objectives are to confirm whether the observed is a common behaviour of terra rossa and to explore the factors controlling the wettability of this soil type after burning. Samples from the upper 2.5 cm of terra rossa were collected from 12 forest sites of the Alicante province (Spain), and from 2 sites in the "Mt. Carmel", Haifa (Israel) with similar environmental conditions. Laboratory burning of samples at 250 °C, 300 °C and 350 °C was performed with and without the addition of litter of *Pinus halepensis*. The results confirm that all soils have a very low susceptibility to become water repellent by burning. Without the addition of litter, WR was not detected in any soil sample at any temperature of burning. With the addition of litter, WR was present only in six of the soils after some of the heating treatments. Although all soils had enough soil organic matter (SOM) to develop WR by heating, the ratio between SOM and clay content was considerably lower compared to other types of forest soils of the region in which WR has been found after forest fires. This could explain in part the lower susceptibility of terra rossa to become water repellent by burning since, as some authors have indicated, fine-textured soils are less prone to develop soil WR due to their high specific surface area. From mineralogical analysis of the clay fraction we found that the dominant clay types in the studied terra rossa were kaolinite and illite, with the exception of one soil where Ca–montmorillonite content is higher than kaolinite and illite. Ca–montmorillonite was present in only three of the soils. Comparing the soil properties between the group of terra rossa that in no case become water repellent (wettables) with the group that in some cases developed WR (potentially water repellents), some differences were found: the kaolinite content is higher in the wettables group ($P<0.05$), and the soils containing Ca–montmorillonite are in the group of potentially water repellents. A clear separation between the 2 groups was found when we compared SOM *vs* kaolinite contents, the kaolinite content being the main factor contributing to this separation. These results are in agreement with those obtained in experiments with clay additions to water repellent soils in order to reduce the WR, and also with some studies which found that kaolinite is one of the most effective clay minerals for this purpose.

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1. Introduction

Soil water repellency (WR) is a common property in fire-affected soils (Doerr et al., 2000). Burning of litter and soil organic matter in a range of temperatures produces hydrophobic substances (Savage, 1974; DeBano et al., 1976). In the soil, WR can produce a reduction in infiltration rates, enhance runoff and erosion, and can also affect the re-establishment of vegetation because of the reduction of water availability (see review of Doerr et al., 2000).

Studies show that when a forest soil is burned at certain ranges of temperatures most develop WR (e.g.: DeBano and Krammes, 1966; Doerr et al., 2004; García-Corona et al., 2004). However there are a few cases, where no changes in WR after burning have been observed (Giovannini and Lucchesi, 1983; Busse et al., 2005). In these last cases it was argued that this could be due to the relatively high clay content of the studied soils.

A background of some previous observations under laboratory conditions (Arcenegui et al., 2007), and in one of the study areas after wildfires (Arcenegui et al., 2008) in terra rossa soils led us to suspect that the intrinsic characteristics of this type of soils provide a relatively low susceptibility to develop WR by burning compared with other types of forest soils of the region.

Factors such as organic matter and clay content have been described as factors controlling the WR developed by burning (DeBano, 1981, 1991). The mineralogy of clay could also be playing

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Table 1
Main characteristics of the sampling sites

Soil reference	Site	Location (UTM) zone/*X*/*Y*	Vegetation (main species)	Geological substratum	Soil classification (Soil Survey Staff, 2006)
North Alicante — South-east Spain					
1	Montgó 1	31/254213/4299993	*Pinus halepensis*	Cretaceous limestone	Lithic Rhodoxeralf
2	Montgó 2	31/248272/4300592	*Pinus halepensis, Quercus coccifera*	Cretaceous limestone	Lithic Rhodoxeralf
3	Montgó 3	31/248478/4300471	*Pinus halepensis, Quercus coccifera*	Cretaceous limestone	Lithic Rhodoxeralf
4	Montgó 4	31/249360/4299160	*Pinus halepensis*	Cretaceous limestone	Lithic Rhodoxeralf
5	Jalón	31/240800/4291100	*Pinus halepensis, Quercus coccifera*	Cretaceous limestone	Lithic Rhodoxeralf
6	Lliber	31/241560/4292965	*Pinus halepensis*	Cretaceous limestone	Lithic Rhodoxeralf
7	Gata	31/242275/4293400	*Pinus halepensis*	Cretaceous limestone	Lithic Rhodoxeralf
8	Moraig	31/253865/4288813	*Pinus halepensis*	Cretaceous limestone	Lithic Rhodoxeralf
9	Benifallim	30/726292/4280035	*Pinus halepensis, Quercus ilex*	Cretaceous limestone	Lithic Rhodoxeralf
10	Mariola	30/707897/4290641	*Pinus halepensis, Quercus ilex*	Cretaceous marl- limestone	Lithic Haploxeralf
11	Biar	30/700146/4282283	*Pinus pinea*	Cretaceous sandy limestone	Lithic Haploxeralf
12	Banyeres	30/705827/4284743	*Pinus halepensis, Quercus ilex*	Cretaceous dolostone	Lithic Haploxeralf
Mt Carmel — North-west Israel					
13	Mt. Carmel 1	36/689666/3625017	*Pinus halepensis, Quercus calliprinos*	Cretaceous limestone	Lithic Haploxeralf
14	Mt. Carmel 2	36/688914/3624165	*Pinus halepensis*	Cretaceous limestone	Lithic Rhodoxeralf

an important role since this has been demonstrated to be a key factor in the alleviation of soil water repellency (McKissock et al., 2000; Dlapa et al., 2004).

Terra rossa is a reddish clayey to silty-clay material, which covers limestones or dolomites in the form of a discontinuous layer ranging in thickness from a few centimetres to several metres. It is also found along cracks and between bedding surfaces of limestones and dolomites. The term "terra rossa" has been commonly used for the red Mediterranean soils derived on hard limestones, and several national soil classifications (e.g. Croatian, Italian, Israeli) have retained the term. The name currently continues to be used by soil scientists, although the term as a type of soils is no longer used as a separate classification group in modern soil taxonomies (e.g.: Soil Taxonomy; WRB classification). In Soil Taxonomy (Soil Survey Staff, 2006) terra rossa is classified as Alfisols (Haploxeralfs or Rhodoxeralfs), Ultisols, Inceptisols (Xerochrepts) and Mollisols (Argixerolls or Haploxerolls). According to the WRB classification (FAO, 2006) terra rossa is recognised as Luvisols (Chromic Luvisols), Phaeozems (Haplic Phaeozems or Luvic Phaeozems) and Cambisols. Thick accumulations of terra rossa like material are situated in karst depressions in the form of pedo-sedimentary complexes (Durn, 2003). Boero and Schwertmann (1989) suggested that the pedoenvironment of terra rossa is characterised by an association with Mediterranean climate, high internal drainage due to the karstic nature of a hard limestone and neutral pH conditions. Moresi and Mongelli (1988) suggested that the nature of the soil formed is a consequence of the dissolution of carbonate and accumulation of insoluble residue in situ through karstic weathering processes in Mediterranean climatic conditions. However some investigations point out that in some places the formation of terra rossa has an aeolian origin (Yaalon, 1997).

The particle size distribution of the insoluble residue of terra rossa is dominated by clay (Durn, 2003). Generally the clay content increases with depth in soil profiles. In some cases a relatively high content of sand sized particles has been observed, and this has been attributed to rhizoconcretions which formed in terra rossa as the result of palaeopedological processes which post-date terra rossa formation (recalcification of terra rossa following its burial) or to recent colluvial additions (Durn et al., 1999).

Scarce data are available concerning the water repellency behaviour of terra rossa to burning (Arcenegui et al., 2007). With the aim of confirming whether the observed response of terra rossa to burning is a common behaviour and to explore the factors controlling the wettability of this type of soils after burning, laboratory controlled experiments have been done with samples of terra rossa from 14 different sites. Additionally some soil physical, chemical and mineralogical analyses have been done in samples.

2. Materials and methods

2.1. Study sites, soils used and sampling

Soil samples were collected from 12 forest sites in the north of the Alicante province (southeast of Spain), and from 2 sites in "Mt. Carmel", in Haifa (northwest of Israel) with similar geological, edaphic and climatic conditions to the north of Alicante province. The main characteristics of sampling sites are described in Table 1. The North of the province of Alicante (Spain) has a mean annual precipitation that varies from 500 mm to 850 mm. Similarly the mean annual precipitation in Mt. Carmel ranges from 500 mm at the coastal plain to 750 mm at the upper elevations (Wittenberg et al., 2007). Terra rossa soils, as in the entire Mediterranean region are also represented

Fig. 1. A representative example of terra rossa soil profile of this study. The typical discontinuous layer ranging in thickness can be observed. Soil profile from site 4, Montgó 4 (Lithic Rhodoxeralf). Photography by J. Mataix-Solera.

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