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MICROMORPHOLOGICAL ANALYSIS OF A TERRA ROSSA SOIL UNDER OLIVE CROP; PEDOGENESIS AND PEDOTURBATION

ANALYSE MICROMORPHOLOGIQUE D'UNE TERRA ROSSA SOUS OLIVERAIE; PEDOGENESE ET PEDOTURBATION

ANALISI MICROMORFOLOGICA DI UN SUOLO AD OLIVETO SU TERRA ROSSA; PEDOGENESI E PEDOTURBAZIONI

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Summary

Permanent tree crops can deeply modify the soil features produced by the pedogenesis processes. Clear microstructural differences were observed in two soil profiles sampled in an olive grove near~~by~~ Sassari (Sardinia, Italy), one under the canopy and one between the tree rows, related either to ~~both~~ the farming practices or to the biological activity in the rhizosphere soil.
Key words: *Terra Rossa, olive-grove, micromorphology, pedoturbation*

Resumé

Les cultures arborées à cycle long peuvent modifier profondément les résultats de la pédogenèse. L'étude de deux profils dans une oliveraie située dans les environs de Sassari (Sardaigne, Italie) - le premier sous feuillage et l'autre entre deux rangées **-** a mis en évidence de clairs effets microstructuraux, en relation soit avec les pratiques agricoles, soit avec l'activité biologique au niveau du sol rhizosphérique.
Mots-clés: *Terra Rossa, oliveraie, micromorphologie, pédoturbation*

Riassunto

Le colture arboree a lungo ciclo possono modificare profondamente le caratteristiche pedologiche prodotte dalla pedogenesi. In due profili studiati in un oliveto nei pressi di Sassari, uno sotto-chioma ed uno nell'interfilare, sono stati osservati evidenti effetti microstrutturali, originatisi sia a seguito delle operazioni colturali, sia per effetto dell'attività biologica nel suolo rizosferico.
Parole chiave: *Terra Rossa, oliveti, micromorfologia, pedoturbazione*

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Introduction

The olive tree (*Olea europea*) is a traditional Mediterranean crop (Loumou and Giourga, 2003; Barbera and Dettori, 2006). It is relatively not exigent in terms of nutritional elements and water requirements, and, for these reasons, up to a recent past, it was often grown in marginal areas. In many Mediterranean regions it is typically associated with Terra Rossa and calcrete soils (Erel Y., et al., 1997; Bogunovic M., et al., 2009; Wagner S., 2009). where it became a permanent element of the landscape over the centuries and played an influence on the development of the soil features.
The effects of olive trees and root systems on the soils have been studied by (Miedema R., 1997), whereas the micromorphological effect in the olive rizhosphere was indagated by very few authors.. (Fernandez J.E., et al, 1991; Dichio B.,et al., 2002).
The present study is part of a wider research initiative involving both Italian and Turkish teams and aimed at understanding the micromorphological effects of the traditional Mediterranean tree crops on Terra Rossa soils (included in the Rhodoxeralfs, according to Soil Survey Staff, 2010).
More specifically, the objective of the study is to analyze the micro-morphological effects induced by long term olive groves on a Terra Rossa rizhosphere soil.

Materials and methods

The study area is located in an olive grove nearby Sassari (NW Sardinia, Italy). The elevation of the study area is about 110 m a.s.l., the morphology is flat to gently undulated. The bedrock is Miocene yellowish-brown compact limestone, with a content of less than 0,1% of almost colorless, sharp edged quartz crystals. According to Ginesu (personal communication) this formation is related to a shallow marine sedimentation environment, without significant inputs of river transported materials. It is part of a more than 200 m deep Miocene sedimentary sequence including crystalline limestone, sandstone, compact gray marl, formed during the Miocene in a large, north-south oriented graben which affected the Sardinia island (Pietracaprina, 1962). The average annual rainfall is around 600 mm.
The age of the olive grove is around 150 years. Two soil profiles were described, where the first was under canopy and around the trunk, observed for the main root system growth and subjected to manual farming practices, whereas the second was sampled between the trees, about 2,5 m from the previous, subjected to annual green manuring. Both profiles have been classified as Typic Rhodoxeralfs (Soil Survey Staff, 2010) with a Ap1-Ap2-Bt1-Bt2-R horizon sequence and a depth of 80 – 85 cm under canopy and 80 – 95 cm between the trees. Horizons have been sampled for physical and chemical analysis and undisturbed aggregates were collected for micro-morphological characterization by thin sections and SEM analysis. For the latter, the samples were made of minute undisturbed aggregates, about 1 cm in diameter. Some of these were composed of biostructures built by

annelids (worm cast), other were consisting of minute aggregates clinging to the roots. Thin sections were described according to Bullock et al. (1985), FitzPatrick (1984; 1993) and Brewer (1964; 1976). The micromorphological analysis was focused on the microstructure (MS) and the microstructural units (MSU) in the different horizons, to highlight aggregate development, distribution and incorporation organic matter, stress and illuviation coatings, nodule and concretion development, faunal activities and new mineral formation.

Results and discussion

The results of the physical and chemical analyses are given in Table 1, whereas the results of the micromorphological analysis are synthesized below, horizon by horizon.

Table 1 - *Physical and chemical properties of the two profiles*

	Profile 1				**Profile 2**			
	Ap1	Ap2	Bt1	Bt2	Ap1	Ap2	Bt1	Bt2
Lower boundary (cm)	10	20	49	80/85	10	30	50	80/95
Rock fragments (>2 mm) (g/Kg)	96	4	4	0	92	21	0	2
Very coarse Sand (2÷1 mm) (g/Kg)	13	12	13	10	15	13	8	9
Coarse Sand (1÷0,5 mm) (g/Kg)	19	24	18	20	20	31	20	18
Medium Sand (0,5÷0,25 mm)(g/Kg)	58	65	55	61	62	70	62	61
Fine Sand (0,25÷0,02 mm) (g/Kg)	331	293	304	282	351	293	305	307
Total Sand (g/Kg)	421	394	390	373	448	407	395	395
Silt (0,02÷0,002 mm) (g/Kg)	356	288	268	257	354	295	288	254
Clay (<0,002 mm) ì(g/Kg)	223	318	342	370	198	298	317	351
pH (H20)	7,1	7,1	7,7	7,9	7,1	7,1	7,5	8,0
pH (KCl)	6,9	6,8	6,5	6,5	7,1	7,1	6,8	6,7
$CaCO_3$ tot (Dietrich-Fruehling calcimeter) (g/Kg)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
OC (Walkley-Black) (g/Kg)	47	41	12	11	44	30	17	9
N tot (Kjeldahl) (g/Kg)	2,2	1,8	1,0	1,0	2,3	1,8	1,2	1,0
C/N	21	23	12	11	19	17	14	9
P_2O_5 (Olsen) (mg/Kg)	20	5	3	3	17	4	5	4
Ca^{++} (meq/100 g)	23,39	22,30	20,27	20,27	25,50	24,17	21,83	19,80
Mg^{++} (meq/100 g)	1,80	1,54	1,29	1,29	1,29	1,03	1,03	1,03
Na^{++} (meq/100 g)	0,54	0,49	0,60	0,65	0,27	0,33	0,49	0,22
K^{++} (meq/100 g)	0,74	0,48	0,29	0,13	0,58	0,45	0,16	0,06
Sum of exch. Cations (meq/100 g)	26,47	24,81	22,45	22,34	27,64	25,98	23,51	21,11
CEC (Cl_2Ba and Triethanolamine method) (meq/100 g)	26,7	25,0	22,6	22,6	27,7	26,1	23,8	21,3
BS (%)	99	99	99	99	100	100	99	99
Exch. Acidity (meq/100 g)	0,23	0,19	0,15	0,26	0,06	0,12	0,29	0,19

Macrostructure

In both profiles macrostructure is prismatic to angular blocky intergrading to crumb/granular structure in Ap1 and Ap2 horizons with partly compacted

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consistent structural units. In Bt1 and Bt2 horizons the structure is similar to the upper horizons but with higher consistency.

Microstructure

Ap1 horizons. The MS of the horizons is partly massive and partly complex, with rug rose-welded crumb granular, and partially accommodated. In P1 some MsUs consist of lignified plant residues and oriented aggregates by shrinkage and swelling activity. The crumb structures are dominant in the worm casts which include mineral grains and compound aggregates (figure 1).

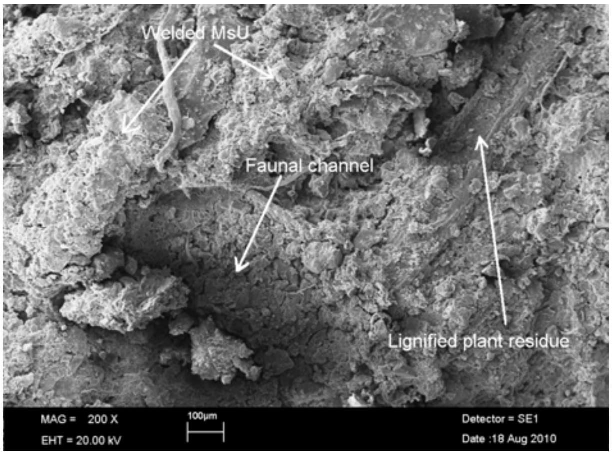

Figure 1

Faunal channel in welded crumb MsU. Sem image

In P2 the faunal activity is frequent and the clay matrix coatings (illuvial) are rare but frequently broken by shrink-swell activity (figure 2).

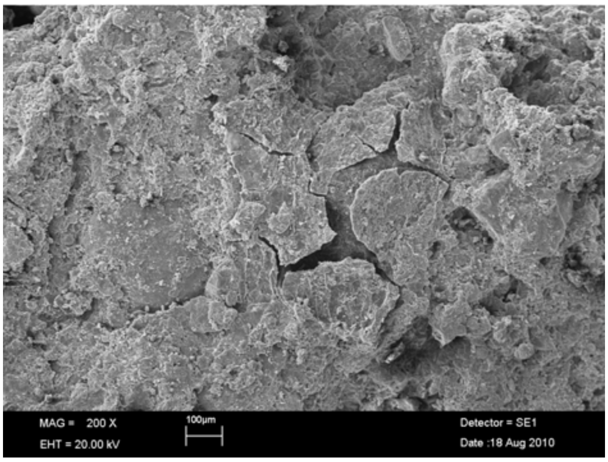

Figure 2

Broken clay coatings (illuvial) by stress activity. SEM image

Ap2 horizons. In P1 the rug rose-welded crumb granular Ms are partially accommodated and incomplete or moderately developed to sub-angular blocky (figure 3).

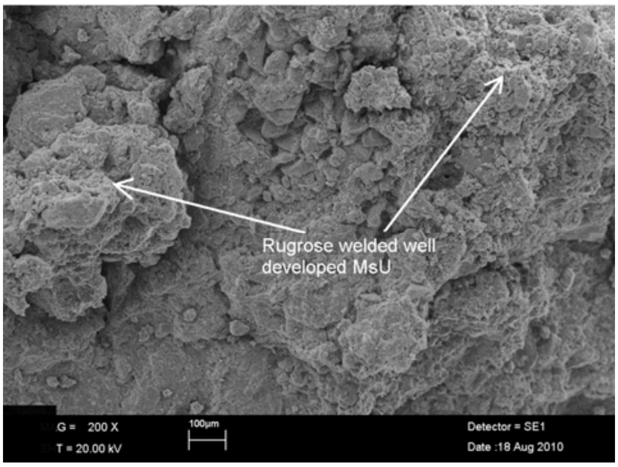

Figure 3

Rug rose-welded well developed MsU's/aggregates. SEM images

Anisotropic reticular or stipple speckled stress features or coatings induce the development to rounded or sub rounded MsU (Kapur et al. 1987). Earthworm activities are frequent, but the 1-5 µm size channels are reworked by smaller earthworms and infilled by soil fragments (figure 4). In P2 the Ms is partly massive, and the rug rose-welded crumb aggregates include decomposed fine roots coated by repeated clay minerals.

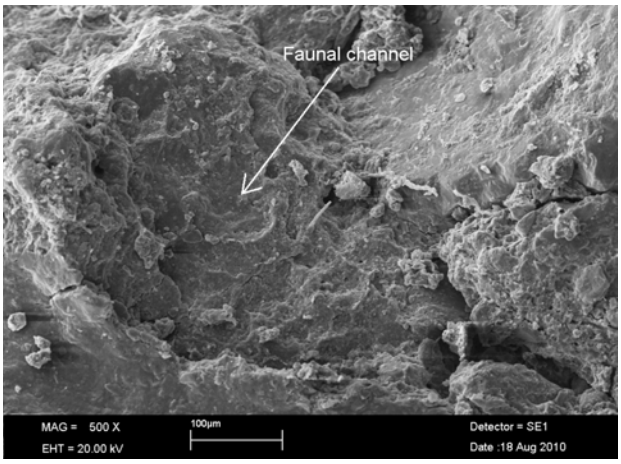

Figure 4

Faunal channel infill of reworked faecal pellets by smaller worms. SEM image

Bt1 horizons. Ms partly massive and partly complex. Ms with welded crumb, granular and partially accommodated subangular blocky. In P1 the MsU are incomplete, rounded to oval, developed by abundant stress features and linear oriented clay domains forming faces of MsUs (FitzPatrick, 1983). The rounded to oval MsUs (more than in the Ap horizons) may stand for the permanent microstructural units or aggregates (figure 5), determined in N.E. Anatolian

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Vertisols by Kapur et al. (1987), together with stipple speckled-b-fabric (Bullock et al., 1985) in red to reddish brown (2,5 YR ¾ Munsell notation) composite colored matrix.

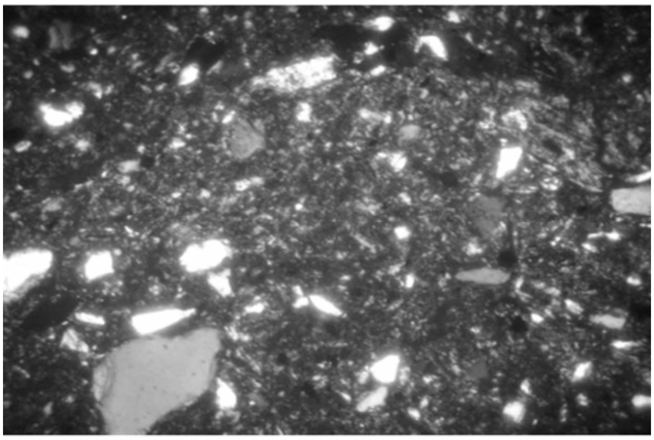

Figure 5

Permanent MsU with reticulate stress features in reddish matrix (XPL, mag 100X)

Degradation of the stress phenomena may be attributed to the vigorous faunal activity, determined by the abundant faunal channels, and excrements.
In P2, Ms is similar to P1, but the complex Ms is composed of welded crumb, granular and partially accommodated subangular blocky wedge like MsUs. In the faunal channels, excrements/pellets are associated with decomposed roots intergrading clay aggregates and MsU crumbs. Fungal hyphae and the clayey matrix form the welded permanent MsU's adjoining aggregate surfaces and minerals (figure 6).

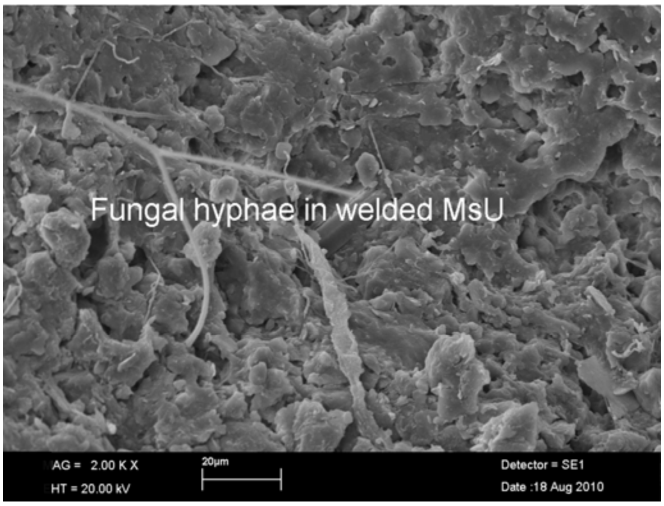

Figure 6

Fungal hyphae and welded permanent MsU's. SEM image.

Bt2 horizons. Ms are similar to Bt1 horizons. In P1 the rounded to oval MsUs are more common than the Ap horizons. Rare, broken clay coatings (ferri-argillans) in

matrix and along the cracks indicate the degradation of these features in the course of long-standing soil formation.
The presence of occasional fibrous and cellular fragments, indicate a probable fire or stubble burning at the earlier management of the field.
In P2, Bt2 is similar to profile 1, except for the absence of fibrous and cellular fragments.

Differences and similarities between the profiles
Increased presence of fungal hyphae in P2 and the development of crumb and granular aggregates are more evident in the P1 profile.
All horizons, except Ap2 of profile P1, contain stress coatings, whereas illuvial clay and humus coatings were observed in the Ap2 horizon of the P2, along with clay mixed with broken clay stress coating in the Bt1 and the Bt2 horizons.
The activity of micro fauna, is similar in P1 and P2 and more abundant in Bt2 of P2. Both Ap and Bt horizons show the presence of concentric black to reddish iron nodules (figure 7), which in Ap1 of P2 consist of coatings of humic substances.

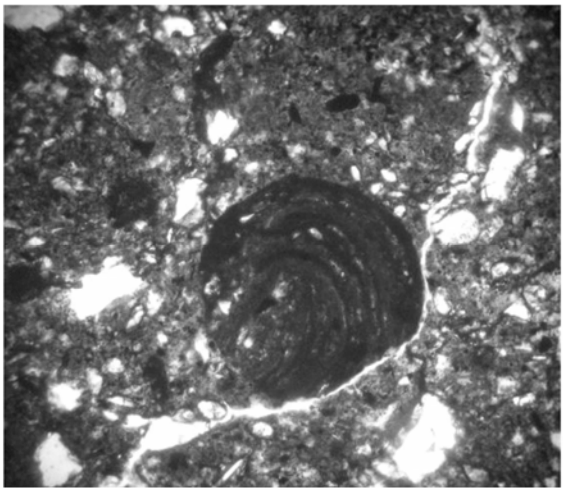

Figure 7

TS 14. Concentric iron nodule (PPL, mag. 25x).

In Ap2 of P2, amorphous iron and humic substances with organic coatings overlie clay coatings (ferri-argillans) indicating formation of clay and organic material illuviation in the earlier stages of profile development.
Both in thin sections and SEM images rare to occasional, irregular to sub-rounded nodules of marine limestone are observed with micritic calcite infills in cracks (figure 8) which indicate a process of decalcification of primary limestone rock fragment and the subsequent calcification.

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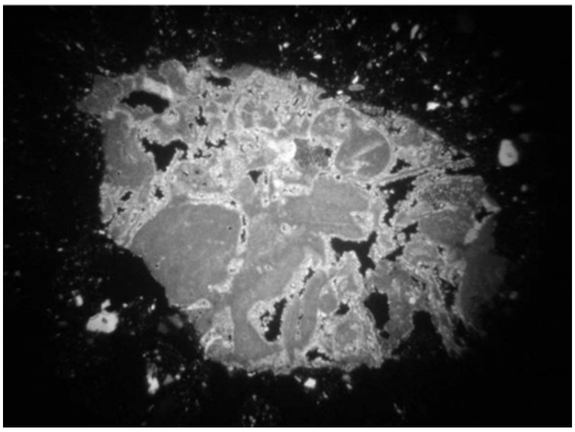

Figure 8

TS3. Carbonate nodule with micritic crack in fills (XPL, mag. 25x).

The low amount of the calcite grains in the profile and the secondary crack infills of calcite, may point to a different source for carbonate along with the inherited. Thus, the fresh rounded occasional to rare, most probably inherited, limestone fragments and the decalcified nodules reflect a complex soil development. The presence of the inherited angular to sub-angular and irregular to sub-rounded quartz grains of very fine (about 5 to 10 microns) to coarser sizes (10 to 200 microns) with collision features (figure 9) are also indicative of this complexity of soil formation.

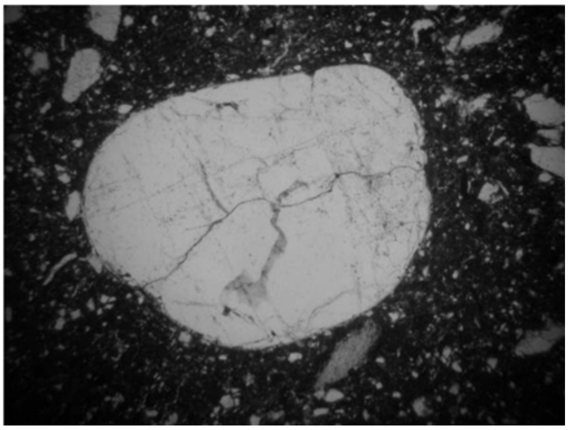

Figure 9

TS 11. Rounded quartz grain with collision features (XPL, mag. 25x).

The presence of these grains is a possible confirmation of the significant role, of windblown material from the Sahara, in the formation of Terra Rossa (Yaalon and Ganor, 1973; Yaalon, 1987; Muhs et al., 2010; Andreucci et al., 2011).

Conclusions

The micromorphological analysis showed that the stress developed by roots and by repeated agricultural practices have produced deep effects on the soil

microstructure, including the almost complete disappearance of illuvial clay coatings and the formation of laminar stress coatings.
Traces of the ancient and polycyclic pedogenetical processes are still abundant and are represented by the iron nodules observed in all Ap and Bt horizons, along with the presence of iron and humic materials overlying coatings in Bt2 horizons. The presence of fine and very fine quartz grains, probably windblown, and micritic calcite crystals in carbonate nodules, is the evidence of the role exerted by the allochtonous contributions to the evolution of the Terra Rossa soils.

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