A micromorphological approach to soil rhizosphere characterisation of an agro-pastoral environment

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Abstract
This research aims at characterising some aggregates and their intra-porosity in paired pasture/maquis plots in a Mediterranean area (Sardinia, Italy). Surface horizons were sampled for thin sections analysis. Macroaggregate shape was compared and intra-porosity was studied for representative aggregates at different depths. The interaction of root activity and grazing under pasture and maquis cover is discussed.

Key Words
Microporosity, aggregate shape, root activity, deforestation, overgrazing, Mediterranean.

Introduction
Soil structure and in particular the pore space system has been the concern of numerous earlier studies dealing with the effect of cultivation techniques and crop types experimented at field sites. Recent long-term-experiments have documented the evolution of specific features related to land use, namely as the spheroidal or the onion skin, and vermicular microstructures (Kapur *et al.* 1997). Stoops' (2003) statement on the existence of infinite numbers of microstructure types at the same and at different scales of observation as well as the commonly occurring phenomenon of juxtaposition on the same level of observation, manifests the difficulty in determining the suite of microstructure typologies in any soil system. The present study aims at characterising some aggregates and their intraporosity in three couples of paired pasture/maquis plots in a Mediterranean area (Irgoli Municipality, Sardinia, Italy). Profiles studied in this paper were earlier described and soil degradation indicators were determined to assess the land use impact by Zucca *et al.* (2009). That study described the unsustainability of the current agropastoral practices, based on clearing of the natural vegetation and by periodic (every 3 to 5 years) ploughing and grazing.

Materials and methods
The thin sections of this study were collected from the same profiles of Zucca *et al.* (2010) and synthetically described in Table 1. Surface horizons were sampled for analysis and thin sections preparation. The soils were developed on "coarse-grained Palaeozoic granites associated with pegmatites and microgranites; white granites with micas/chlorites and their migmatites", generally termed as metamorphic schist or gneiss due to their uniform nature that developed following metamorphism. Soils studied are shallow (no more than 20-35 cm to the lithic contact), sandy loam, loam, or sandy clay loam, weakly acid moderately saturated. Pasture soils show different degrees of erosion and degradation. The micromorphological approach adopted for this study consisted of the determination of the shape (regularity/roundness increases to around 1.00) and the intra-porosity of selected aggregates, that may reflect the characteristics of the horizons and pore distribution in the rhizosphere (A and/or AB horizons). The description of the microstructure was undertaken according to the relative distribution of coarse to fine constituents as stated by Stoops and Jongerius (1975) later adapted by Bullock *et al.* (1985).The study was conducted on thin sections (8x5 cm) obtained from 6 undisturbed samples collected from the surface horizons of the different profiles. The thin sections were divided into 3 parts from 0 (surface of the thin section) up to 2 cm, from 2 to 4 cm and from 4 to 6 cm (Figure 1). In each part, representative aggregates (up to a size of 4.9 x 3.7 mm, corresponding to the maximum extent allowed by the optical acquisition system), were digitized for intra-porosity measurements. The analysis was undertaken according to Pagliai *et al.* (2004) and Pagliai (1988) by the software Image Pro Plus. The shape of the aggregates was determined by the Perimeter Convex/perimeter relationship.

Results and discussion
Profile 1: 2AP (Pasture)
The porphyric single space matrix and the dominant moderately developed incomplete subangular fine to

very fine weakly to moderately accordant microstructure (units/aggregates of 3 to 5 mm size) developing from the strongly weathering rock matrices with a continuous rock/soil phase and numerous sinuous bifurcating pores. Pores of <50 micron size increased at 0-2 cm and 2-4 cm depths, whereas a decrease of this size and an increase of larger pores were determined at 4-6 cm. This may reflect the higher influence of the roots at the top 4 cm and a probable compaction at the lowermost part of the surface horizon. The higher amounts of the elongated pores in this size range may also relate to the root action in the rhizosphere. The sum of the intra-aggregate porosity also indicates to the increased overall porosity in the 0 to 2 cm depth. This ties in well with the shape of the aggregates developing more rounded/regular in the 0 to 4 cm depths compared to the irregular aggregates of the 4 to 6 cm (Figures 2, 3a and 3b).

Table 1. The studied soil profiles. P = Pasture; Md = degraded Maquis. Classification according to USDA (1999).

	Plot	Profile N	Horizons	A hor. depth	Classification	% C	C/N
Site 2A; pastures cleared in late 1980s; slope 40%	P	1	AC	11cm	Lithic Xerorthents	2.0	25
	Md	2	ABwBC	10cm	Lithic Dystroxerepts	6.8	16
Site 1A; pastures cleared in 1970s; slope 35%	P	4	AC	9cm	Lithic Xerorthents	2.6	14
	Md	5	AC	10cm	Lithic Xerorthents	5.3	22
Site 1B; pastures cleared in 1970s; slope 30%	P	6	ApC	18cm	Lithic Xerorthents	2.6	15
	Md	7	AC	10cm	Lithic Xerorthents	5.4	20

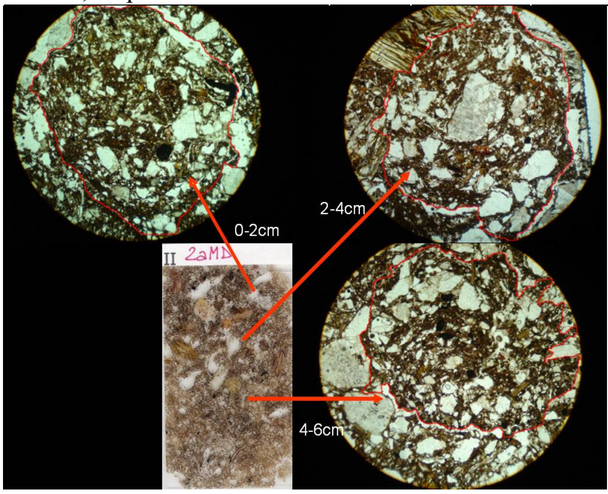

Figure 1. Selection of representative aggregates for the intra-porosity analysis of profile 2 (2AMd).

Profile 2: 2AMd (Degraded maquis)

The porphyric double space to enaulic matrix of crumby microstructure with voids and channels consists of moderately developed aggregates of 0.1 to 3 mm sizes. Pores of <50 micron size are dominant throughout the 0-6 cm part of the rhizosphere, followed with an increase of 100 to 200 micron pores in the 2 to 4 cm depth. The lowermost 4 to 6 cm part contains all sizes of pores with the dominant 50 to 200 micron size range (Figures. 1 and 3a and 3b). The elongated pores are higher in the 0 to 4 cm range, whereas the irregular (angular) increase at 4 to 6 cm. The situation for the pore shape distribution in this horizon reflects the effect of the root activity down to 4 cm. The gradual increase of the overall porosity may also indicate a strong root activity increase with depth. Aggregate shape tends to remain more rounded-regular at the 0-4 cm depth and shifts to higher irregularity in 4 to 6 cm depth (Figure 2).

Profile 4: 1AP (Pasture)

The porphyric single space matrix and microstructure is characterised by channels with moderately developed weakly separated aggregates of 0.1 to 3 mm sizes revealing a slight trend of decrease of regularity (roundness) with depth. Image analysis revealed that pores <50 micron were dominant throughout the 0-6 cm depth of the rhizosphere (as it is in the profiles above), with decreasing number of irregular pores from 0 to 6 cm, and an increase of elongated (micro-cracks) in 2 to 4 cm. The regular, irregular and elongated pores were about at equal amounts at 4 to 6 cm depth. The overall porosity of this horizon seems to be the lowest among all the studied horizons as is also reflected by the virtual absence of the majority of pore sizes (Figure 3a). The aggregates also show a slight decrease of regularity (roundness) with depth. The effect of the roots seems to be higher in mid horizon as manifested by the increasing elongated pores (Figures. 2 and 3b).

Profile 5: 1AMd (Degraded maquis)
The porphyric single space matrix contains a crumby subangular blocky to irregular microstructure and moderately distributed voids and canals. The moderate to rare distribution of the voids is also reflected by the sum of the low intra-aggregate porosity compared to 2AP and 2AMd (Figure 3a). The strongly developed and weakly separated aggregate sizes are 0.1 to 3 mm in size and intergrade to irregular with depth (Figure 2). The dominant pore size is <50 microns throughout the thin section with the elongated ones intergrading to irregular, similar to the aggregates, with depth (Figure 3a and 3b).

Profile 6: 1BP (Pasture)
Porphyric single space to enaulic matrix and microstructure with intergranular microaggregates intergrade to strongly developed, weakly separated crumby (0.05 - 3 mm size). Pores of <50 micron size (dominantly elongated) were determined to be dominant from 0 to 4 cm, whereas the >500 micron irregular pores, expected to increase permeability, increased at 4 to 6 cm depth. The shapes of the aggregates intergrade to irregular, parallel to the pores, from more rounded with depth at 4 to 6 cm (Figures 3a, 3b and 2).

Profile 7: 1BMd (Degraded maquis)
The enaulic to porphyric single space matrix with frequent crumby intergranular microstructure and strongly developed, weakly separated microaggregates of 0.05 - 2 mm size manifest an increased regularity with depth in contrast to the other horizons (Figure 2). The dominantly elongated <50 micron pores (0 to 2 cm) and almost all the other sizes of pores show a decrease at 2 to 4 cm and a consecutive increase at 4 to 6 cm depth as also reflected in the overall porosity (Figures 3a, 3b and 2).

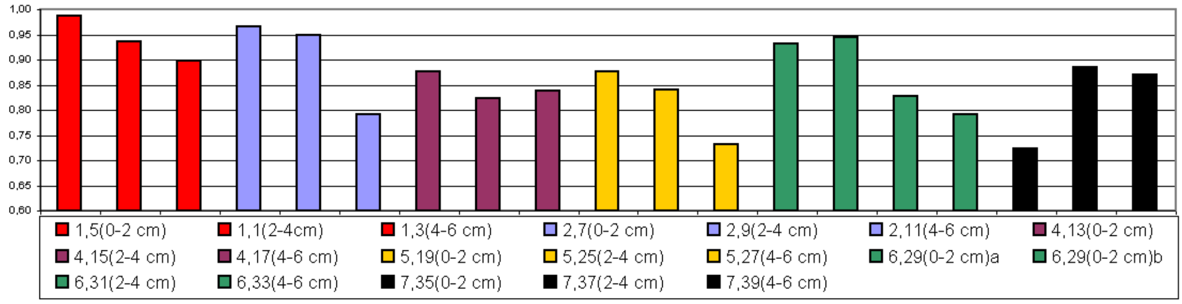

Figure 2. Shape analysis of the aggregates (regularity/roundness increases towards 1.00 per Convex/Perimeter).

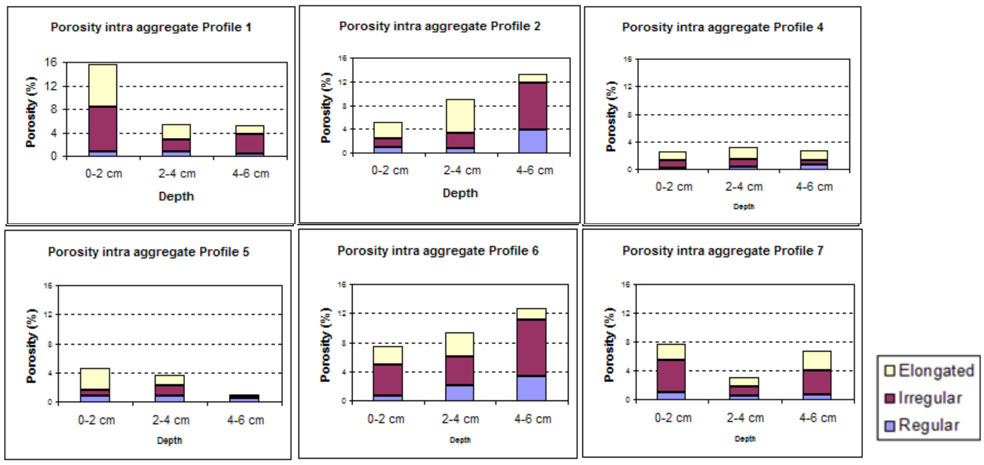

Figure 3a. The sum of the total porosity.

Conclusions
The sum of the total porosity of 2AMd (Maquis) and 1BP (Pasture) revealed an increase in pore percentage from 0 to 2 cm to 4 to 6 cm depth reflecting the increasing activity of the roots with depth, whereas 2AP (Pasture) and 1AMd (Maquis) show an opposite trend, which may point out to the decreasing influence of the roots and the higher effect of the finer 0-2 cm depth roots. The fluctuations in total porosity, also in the light of the 1AP and 2BMd values, seem to be related both to vegetation cover type and to the effects of grazing, which might induce or inhibit the development of the under and/or over-ground biomass. The <50 micron pores are dominant in 1AP (all layers), 2AMd (all layers), 2AP (0-2, 2-4 cm), 1AMd (all layers), 1BP (0-2, 2-4 cm) and 1BMd (all layers), whereas in 2AMd and 2AP, the 100 to 200 micron pores are high at 2-4 cm and 0-2 cm depths. The pores of 400-500 and >500 are dominant in 1BP, where the latter (4-6 cm) is the

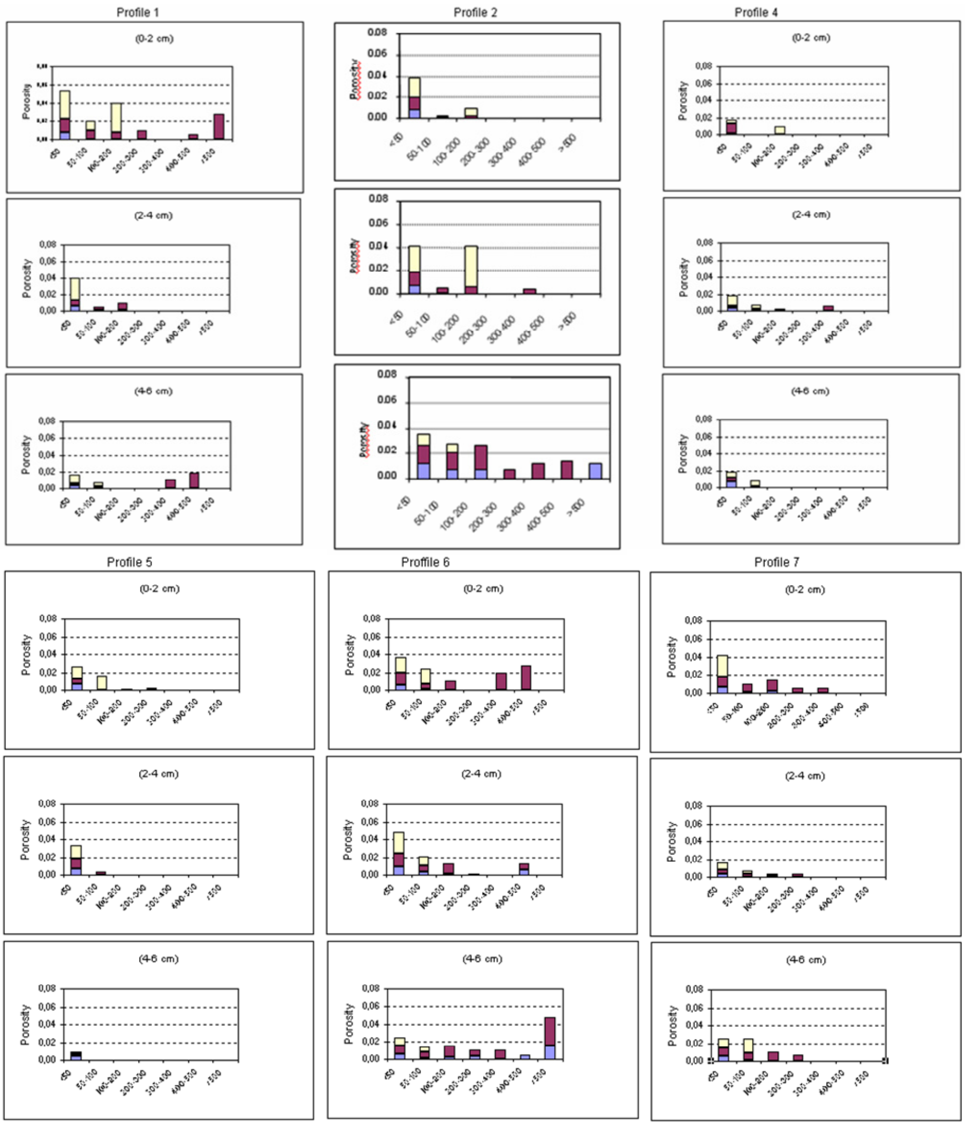

Figure 3b. The pore characteristics of the soils, by pore size class (in microns).

highest compared to the other profiles. The dominance of pores <50 micron under pasture and the highest values in the 0-2 and 2-4 depths of 2AP and 1BP, can indicate a positive contribution of the pasture vegetation to soil porosity but also a relative surface compaction effect due to grazing. The shape analysis of the aggregates of 2AMd, 2AP and 1BP also manifests the importance of pasture vegetation versus maquis.

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