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SOIL MACROPOROSITY EVALUATED BY A FAST IMAGE-ANALYSIS TECHNIQUE IN DIFFERENTLY MANAGED SOILS

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ABSTRACT: Porosity, pore size distribution and a pore shape factor were measured from resin impregnated soils by means of a fast technique of image analysis. Images are directly captured by a video camera from polished impregnated blocks. Micromorphology was also used to assist in the comprehension of soil porosity changes in three differently managed soils: dry-farming plus tillage, irrigated plus grass-covered, steppe natural soil. Under study, alluvial soils from a semi-arid region in NE Spain.

Even if there are no significative differences in total macro-porosity between the differently managed soils, pore size distributions are significatively different. Both natural and irrigated permanently-covered soils have a larger amount of pores bigger than 1 mm in diameter, most of them of biological origin, greatly favouring aeration. Tillage contributes significantly to change the relative distribution of pore shape: the amount of rounded pores (vughs) decreases and elongated pores as well as fissures appear.

INTRODUCTION

Soil management and tillage influences on soil structure and porosity has been proved by numerous authors (5,8,14)

The use of classical technology in modern agriculture (heavy machinery, production intensification, increase in chemical fertilizers but decrease in organic matter inputs) can result in a generalized soil degradation, especially portrayed by a change in structure related properties. These changes are usually the cause of an increase in vulnerability towards erosive agents (water and wind) and the triggering of other degradative soil processes: hydromorphy, surface sealing, plough pan development, salinization, etc. (18).

As a measure to counteract these processes, the minimumtillage, specially in orchards where soil is permanently covered by grass, seems to favour the recovering of the natural soil properties (18).

Soil porosity, pore size distribution and orientation pattern of pores have revealed to be important parameters to evaluate changes generated in soil structure by tillage (6,12,13,15)

The pore size distribution is one of the most important physical parameters in soils because it controls water storage capacity, water and air circulation, root penetrability and compaction strength. Several authors have classified pores according to their size (2,3,7,9). For the latter author equivalent pore diameters between 0.5 µm and 50 µm correspond to water storage pores, between 50 µm and 500 µm, transmission pores and over 500 µm, aeration pores. The last two classes are considered as macro-porosity.

Most of the authors who use image-analysis for macroporosity determinations make their measurements from photographic images. The seizing of images by a TV camera directly from polished blocks might enable much faster macroporosity determinations with only a little loss in resolution power.

Based on the latter consideration, the aim of this paper is to present that fast method for macroporosity evaluation from polished slices of hardened undisturbed soils, which was applied in three differently managed, semi-arid, alluvial soils from NE Spain. Besides the image analysis of macropores, and with the intention to assist in the comprehension of processes influencing macroporosity evolution, thin sections of impregnated blocks were studied micromorphologically.

MATERIALS AND METHODS

Samples were taken from the surface horizon of soils under three different management types in a variety of situations: two abandoned fields in alluvial soils and considered as "natural soils" (a and b), three irrigated orchards in no-tilled, permanently grass-covered, alluvial soils (c, d, and e) and four dry-farmed fields in alluvial and colluvial soils in which usual tillage was applied (f, g, h, and i). They all belong to the Baix Segre region, under semi-arid climate, in NE Spain.

The soil water regime is xeric near to aridic and the temperature regime is thermic.

Some soil morphological features (structure and porosity) and classification, according to the Soil Taxonomy System (17) are reported in Table I.

Other characteristics related to their chemical properties, such as pH, organic matter, carbonate content, exchange capacity, electrical conductivity as well as their particle size analysis are given in Table II.

Five replicated samples from every soil were taken in Kubiena boxes and then impregnated under vacuum with a polyester resin (Resipol HD-0059) in which a fluorescent dye (Uvitex DB) had been add. Upon hardening, parallel slices from every impregnated block were cut with a diamond disk saw and their faces were polished.

When the polished faces are illuminated with UV light in a dark environment (two 8 watts fluorescent "black lights" have revealed to be enough), only the resin-filled pores appear visible. A video camera (Bosch TYY9B) equipped with a "macro" lens captures the image which is displayed on the screen of a monitor. The video signal is digitally processed by the image analyzer (Kontron-Zeiss Instruments, system IBAS 2000) to give a grey level to every pixel. The task of the operator is reduced to the setting of the grey levels displayed on the screen in order to allow the best discrimination of pores. This operation usually takes less than five minutes as the contrast between the surface occupied by pores and the remaining surface allows an easy distinction. The resulting image can be stored for further processing or be quickly digitally processed with the built-in software of the system. The software allows the automatic measurement of a large amount of parameters, but only three of them have been chosen at this instance:

a) total surface occupied by pores.

b) pore size distribution in 7 classes.

c) circular shape factor (CIRSF), defined as:

> $4 \times \pi \times \text{area} \times (\text{perimeter})^{-2}$, in which 3 classes have been defined according a similar circular shape factor used by Bouma (2):
>
> - rounded pores (CIRSF > 0.503).
>
> - irregular pores (0.188 < CIRSF < 0.503).
>
> - elongated pores (CIRSF < 0.188).

Table I. Morphology and soil classification.

Soil management	Sample	Horizon / Depth (cm)	Soil Classification	STRUCTURE Type and size (mm)	POROSITY Rated porosity	Dominant size (mm)	Dominant orientation	Origin
natural soils	A	A1 (0-15)	Typic xerorthent	SB (5-20)	4	1-5	1	W, R
	B	A1 (0-15)	Calcixerollic xerochrept	SB (5-10)	5	1-2	1,3	W, R
irrigated no-tilled	C	Ap (0-11)	Calcixerollic xerochrept	SB (10-50)	4	2-4	1	R, W
	D	Ap (0-15)	Calcixerollic xerochrept	SB (10-50)	5	1-5	1	W, R
	E	Ap (0-12)	Calcixerollic xerochrept	SB (10-50)	4	1-3	1,3	W, R
dry-farmed tilled	F	Ap (0-11)	Lithic xerorthent	SB (10-20)	3	0,5-3	1	W (R)
	G	Ap (0-12)	Typic Xerofluvent	L (2-7)	2	1-2,5	3 (2)	F(R)
	H	Ap (0-15)	Typic Xerorthent	SB (20-50)	3 - 2	0,5 - 3	1	F(R)
	I	Ap (0-12)	Calcixerollic xerochrept	SB (20-50)	2	1 - 2	1	F(R)

STRUCTURE: SB = subangular blocky, L = platty
RATED POROSITY: 2 = non porous, 3= little porous, 4= porous, 5= very porous.
DOMINANT ORIENTATION: 1= vertical, 2= horizontal, 3= skew.
ORIGIN: W= worms, R= roots, F= fissures.

Table II. Textural and chemical characteristics of the studied samples.

Soil management	Sample	pH	CaCO3 equiv. (%)	O.M. (%)	C.E.C. (cmol/kg)	E.C. S/m	Texture
natural soils	A	8.4	33	4.1	17	0.01	Silty clay loam
	B	8.2	31	4.6	18	0.01	Loam
Irrigated no-tilled	C	8	29	3.1	17	0.01	Loam
	D	7.8	28	3	17	0.02	Sandy clay loam
	E	7.8	28	3.2	18	0.02	Sandy clay loam
dry-farmed tilled	F	8.3	32	1.2	11	0.02	Loam
	G	8.4	33	1.7	20	0.01	Silty clay loam
	H	8.1	33	1.2	12	0.06	Loam
	I	8.2	30	1.1	11	0.01	Loam

The type of the video camera lens (Pentax 50-mm Macro) along with its shortest focus distance, reveal that the minimum information unit (pixel) obtained in the screen equals an area of 89 μm x 89 μm. Consequently only pores larger than 100 μm have been studied.

In every polished face a compact area of 46 x 46 mm was studied.

To ascertain the differences among the studied cases, ANOVA was run with the porosity results in which the average values from 5 replicates were used.

For the purposes of comparison between the micromorphometrical and the micromorphological data, only two pore categories are considered, as in the Beckmann and Geyger (1) classification: vughs and planes. Vughs comprise cavities, chambers and channels (Fig. 3). Vesicles are seldom observed in the presently studied soils. Planes are fissural voids (Fig. 5).

Micromophological analysis was performed through large thin sections made from some of the slices (10). Descriptions were made following the Handbook for Soil Thin Section Description (4).

RESULTS AND DISCUSSION

Total Porosity: The average values of the following parameters indicative of porosity are included in figure 1: number of pores, percentage of surface occupied by pores and surface occupied by 100 pores (100 x "total surface occupied by pores"/"total number of pores").

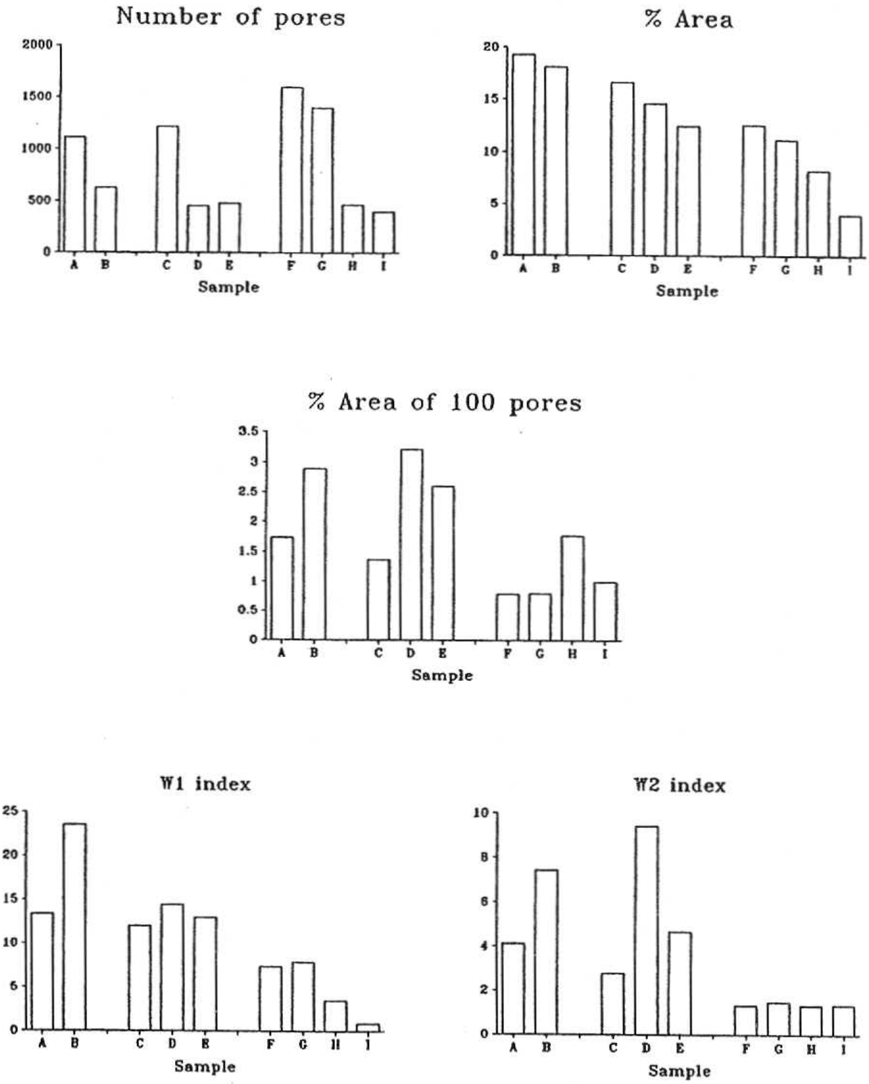

Figure 1. Average values of number of pores, percentage of surface occupied by pores and surface occupied by 100 pores.

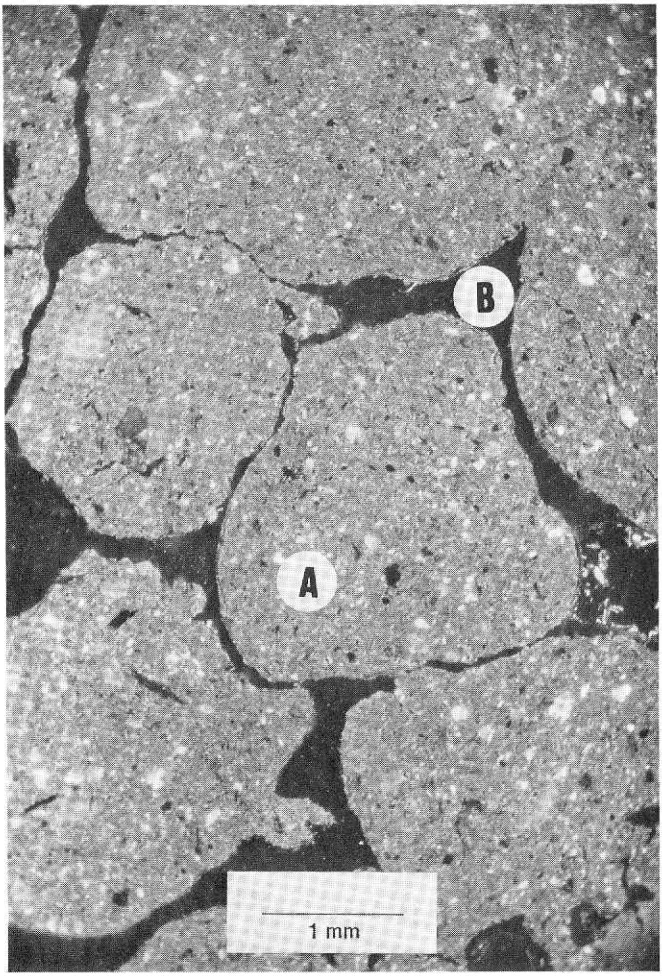

Figure 2. Microphotography of a natural soil, exhibiting a part of a loose continuous excremental infilling. A: excrement; B: void. PPL.

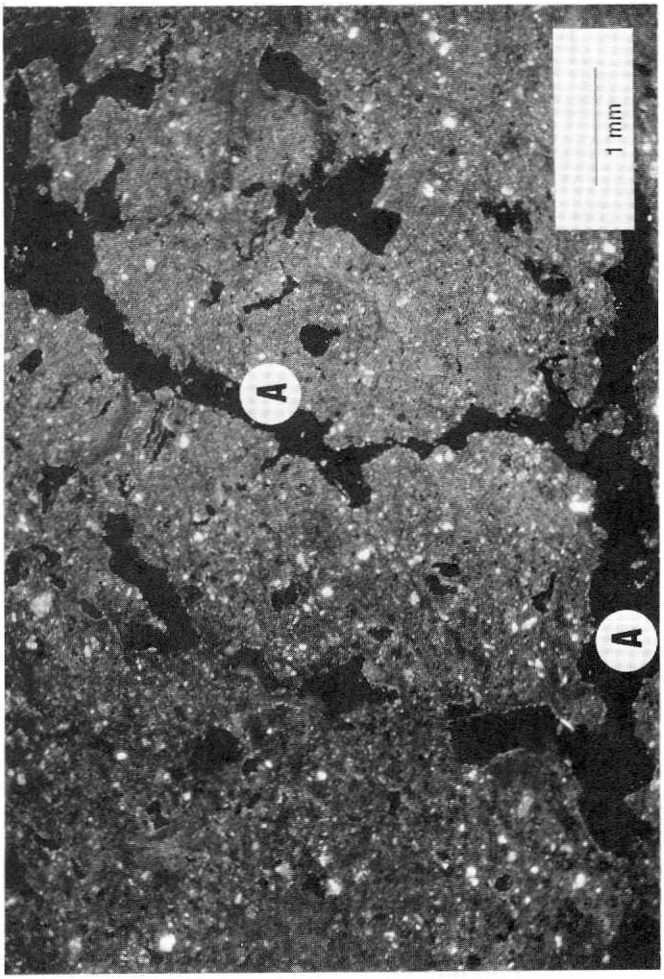

Figure 3A. Microphotography of an irrigated no-tilled alluvial soil: A channels. B: silty-clay infilling in a planar void crossed by a recent void. In this soil, faunal activity is more important than particle translocation. PPL.

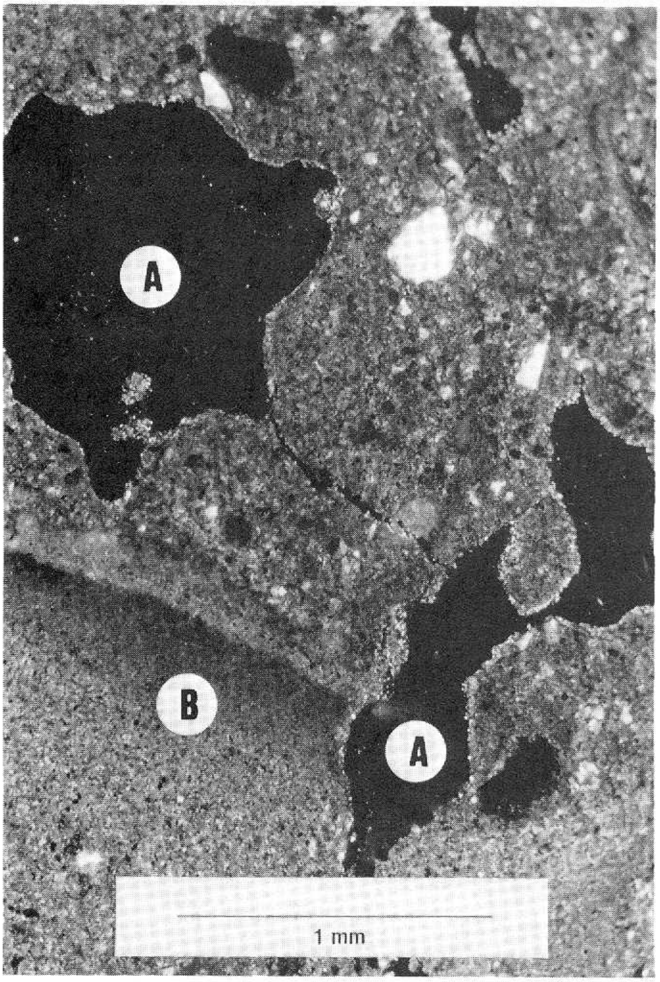

Figure 3B. Microphotography of an irrigated no-tilled alluvial soil. A: channels; B: silty-clay infilling in a planar void crossed by a recent void. In this soil, faunal activity is more important than particle translocation. PPL.

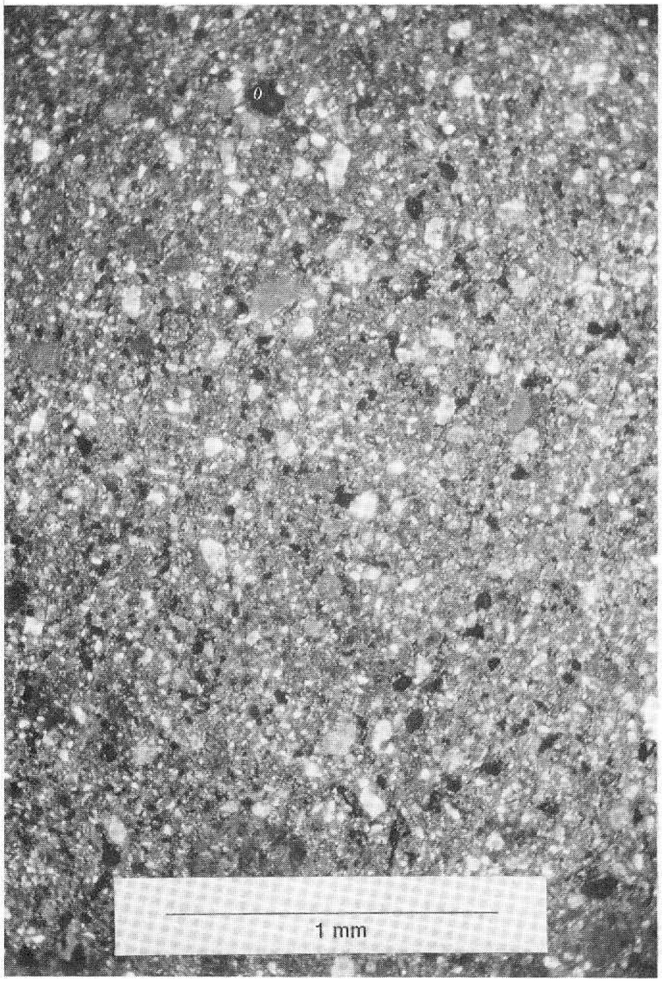

Figure 4. Microphotography of a dry-farmed soil exhibiting its low porosity and poor structure. PPL.

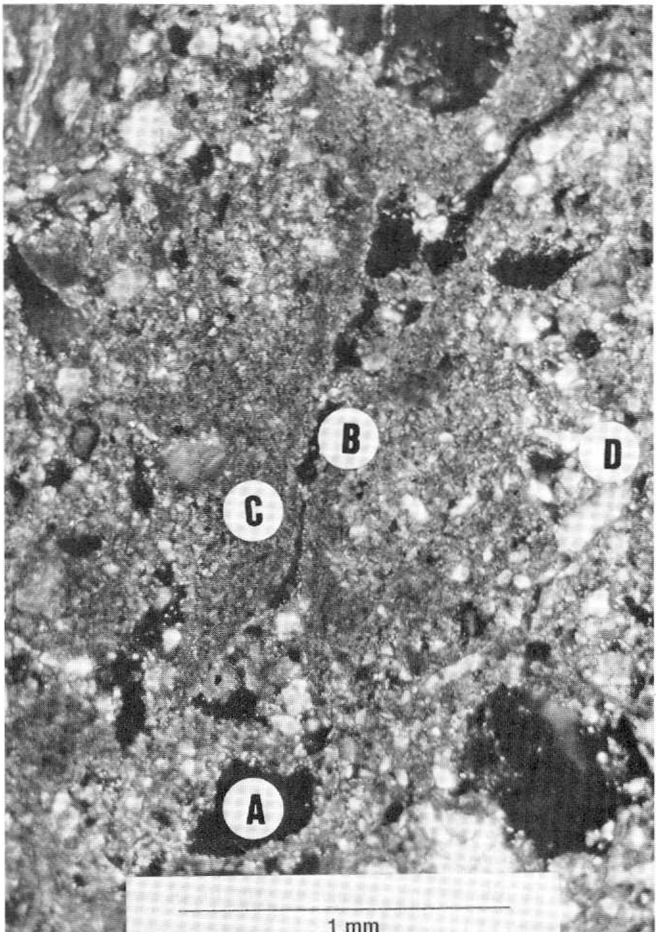

Figure 5. Microphotography of a dry-farmed soil. A: void; B: planar void; C: silty clay coating; D: groundmass. In these soils fine particle translocation is more important than faunal activity. PPL.

The average values of both the relative surface occupied by pores and the surface occupied by 100 pores are high in irrigated-permanently-covered soils, somewhat less in natural soils but quite low in bare dry-farmed soils.

The ANOVA performed with the whole porosity results indicates that there are no significative differences between the three studied cases. However, the relative area show significative differences among the three cases ($p < 0.02$) and the area occupied by 100 pores also show significative differences among the three cases ($p < 0.01$).

There are significant differences between the "natural" and the bare dry-farmed soils ($p = 0.09$) and between the latter and the irrigated-permanently-covered soils ($p = 0.06$). Nevertheless, no significative differences are observed between "natural" soils and irrigated-permanently-covered soils.

The high values in the relative pore surface and in the surface occupied by 100 pores observed in natural and irrigated-permanently-covered soils can be explained by the abundant soil fauna in the surface horizons of such soils. Most of the macropores are due to lumbricus and larvae (Table II). Biological activity is highly correlated with the amount of organic matter of these soils as well as with the amount of roots, as it has been already shown (11,16) in different environments. The porosity differences between natural and irrigated-permanently-covered soils can be ascribed to the fact that the latter are irrigated and as the area is semiarid, water is a restrictive factor in the fauna activity and development.

The relatively low porosity in tilled-soils is probably due to tillage, which has a presumable effect of macropore crushing; moreover, the lack of larvae and lumbricus can be the result either of the tillage destruction or of the low organic matter and root contents (18).

Pore Size Distribution and Shape: "Natural" and irrigated-permanently-covered soils show in all cases an important amount of pores larger than 1 mm (Fig. 1), quite different of that in tilled soils. Furthermore, the W2 index (W2 = pores > 500 µm / pores < 500 µm), is larger in natural and irrigated-permanently-covered soils than in bare dry-farmed soils. By means of ANOVA the significative difference between dry-farmed and natural soils ($p = 0.06$) and between dry-farmed and irrigated-permanently-covered soils ($p = 0.05$) was verified; no significate differences are detected between natural and irrigated-permanently-covered soils.

It is important to stress the abundance of rounded pores in natural and bare dry-farmed soils (Fig. 1).

The WI index (WI Pr/Pe), where Pr is the relative percentage of the rounded pores area and Pe is the relative percentage of elongated pores area) shows a significative difference between bare dry-farmed and natural soils ($p = 0.007$) and between the former and irrigated-permanently-covered soils ($p = 0.04$), and no significative difference between natural and irrigated-permanently-covered soils.

The micromorphological analysis reveals that rounded pores correspond essentially to cavities (vughs) made by worms (mainly lumbricus) and arthropods. Elongated pores correspond essentially to fissures or planes. Irregular pores are formed by the combination of channels and fissures.

Micromorphology and Processes Affecting Porosity: Micromorphological observations reveal the abundance of bioformed pores in natural and untilled soils: faecal pellets, tubules, striotubules and other features made by fauna (Fig. 2). In dry-farmed soils, pores are smaller, mostly packing void and planes (Fig. 3A, 3B).

High macroporosity and the profusion of rounded pores in "natural" soils, along with the scarcity of textural features, indicate the magnitude of biological activity processes over particle translocation processes. In cultivated-permanently-covered soils, both processes seem to coexist, but pedoturbation is more important than particle translocation. The irrigation of these soils has a determinant influence on both processes, by increasing particle translocation and biological activity due to the water surplus.

Still the bioturbation process is probably fast because of the high humidity of these soils and their high organic matter content.

In tilled dry-farmed soils, the low biological activity as well as the large amount in textural features, either infilling voids or capping aggregates and gravels are significant. This is probably due to the action of tillage, which physically pulverizes surface horizons along with the removal of plant cover. When no plant cover is present, raindrop impacts exerts a destroying action on surface clods or aggregates, favouring dispersion and translocation of particles through pores. This process primarily produces laminated micro-pans over cutans and infillings.

CONCLUSIONS

This study highlights that dry-farmed, tilled soils from semiarid Segria present lower macroporosity and hence are more compacted than untilled irrigated soils. Macropores are mainly fissures and packing voids. Biological activity seems to be reduced because tillage destroys channel type pores of biological origin (either from sol fauna and from roots) and leaves a bare soil surface. Soil surface is consequently subject to raindrop impact which causes aggregate disruption. Finer particles are easily washed by infiltrating and runoff waters, and fill up large pores, contributing to reduce macroporosity.

Tillage contributes significantly to change the relative distribution of pore shape: the amount of rounded, natural pores (vughs) decreases and elongated pores as well as fissures appear because of tillage.

A permanently grass-covered soil, either natural or irrigated, has abundant fine and very fine roots in the whole surface horizon and biological activity, under the relatively warm climate of the area, is consequently high: worms and arthropods create a large number of predominantly rounded pores. Irrigation along with a permanent grass cover favour a good structure and aeration.

The micromorphometrical technique employed for this study has revealed to be fast and well-suited for routine macroporosity analysis (from 100-μm pore diameter). Its main advantage, with regard to other similar techniques, is that resolution is maintained in the process of image grabbing, as the image analysis is done directly through a direct video camera. No thin sections are necessary because only polished surfaces of impregnated blocks are used.

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