

COMPTES RENDUS
PROCEEDINGS

VOL 1



XV International Symposium

Gesco 2007

Poreč - Croatia

20. - 23.06.2007



Ministry of
agriculture,
forestry and
water
management

MICROMORPHOLOGY AS A TOOL FOR IMPROVING THE WATER REGIME CHARACTERIZATION OF VINEYARD SOILS

Nadia Vignozzi, Sergio Pellegrini, Edoardo A.C. Costantini, Roberto Barbetti

Istituto Sperimentale per lo Studio e la Difesa del Suolo – Piazza M. D'Azeglio,30 50121 Firenze, Italy.

Corresponding author. Tel.: (+)39-055-2491246; fax: (+)39-055-241485; E-mail address: n.vignozzi@issds.it

Abstract

Soil hydrologic characteristics and water regime are among the environmental factors that mostly affect nutrient and oxygen availability for the vines. As a consequence, they are able to determine stress conditions acting on the plant hormonal equilibrium of each variety, which in turn regulates the expression of the genotype.

The aim of this work was to investigate the relationships between macroporosity and hydrologic characteristics, and to assess whether the standard field appraisal of soil water regime could be improved through the quantitative micromorphological analyses of the pore system by image analysis. The results of field and laboratory analyses were related to macroporosity data obtained by image analysis.

The statistical analysis (PCA) associated the abundance of elongated and irregular macropores to scarceness of redoximorphic features (mottles) and lower bulk density, and to higher soil organic matter content. The quantity of regular pores was on the other hand correlated to an average high soil water content, to a lower mean redox potentials and to higher values of permeability class as evaluated during soil survey (higher values correspond to lower permeability).

Keywords: Soil; Image analysis; Drainage; Sangiovese; Italy

Introduction

Soil hydrological characteristics and water regime contribute to the quality of wine, because they affect nutrient and oxygen supply. The rationale is based upon the observation that environmental factors influence the hormonal equilibrium of each variety, which in turn regulates the expression of the genotype (Van Leeuwen and Seguin, 1997). The frequency and duration of periods of soil wetting are typically estimated in routine soil survey by the "class of internal drainage". This indicator provides a first rough approximation. Several strategies can be applied and combined to

improve the routine estimation. If technical reasons exclude the possibility of a continuous monitoring, as is generally the case in unrestricted and periodically cultivated fields, it is possible to relate field evaluations to measurements of moisture coming from benchmark soils (Costantini et al., 1996), use simulation models calibrated on specific environments (Costantini et al., 2002), perform a number of laboratory tests, e.g. measurements of soil water content at different matric tensions, hydraulic conductivity, etc. Quantitative analysis of the pore system through image analysis is a promising technique enabling a better understanding of soil hydrological properties (e.g., Schaap and Lebron, 2001; Vervoort and Cattle, 2003).

The aim of this work was to investigate the relationships between macroporosity and hydrologic characteristics, and to assess whether the standard field appraisal of soil water regime could be improved through the quantitative micromorphological analyses of the pore system by image analysis on soil thin sections.

Materials and methods

The trial was conducted in the province of Siena (central Italy), on 9 representative fields, situated on 7 farms. The soils of the experimental vineyards (*cv. Sangiovese*) were routinely described, sampled, analyzed and classified according to Soil Taxonomy (Soil Survey Staff, 1999). Besides routine physical and chemical analyses, soils were characterized by bulk density (core method), and by moisture content at field capacity (-33 kPa) and wilting point (-1500 kPa) by Richards pressure plate extractor (Kassel and Nielsen, 1986). A field assessment of soil internal drainage for the whole profile was obtained modifying the attributes suggested by the Soil Survey Division Staff (1993) (Costantini et al, 2006). A field estimation of saturated hydraulic conductivity class of each horizon was obtained following the USDA methodology, based upon specific soil properties, i.e. particle size, structure, consistence, macroporosity, presence of pressure faces and slickensides (Soil Survey Staff, 2001).

Soil water content by the gravimetric method (three samplings with a hand auger), at 0.1-0.3 m and 0.4-0.7 m depth, soil temperature at 0.5 m depth (portable pt100), and redox potential at 0.15 m (hand-held Barnant pH/mV/ORP meter, two measurements) were measured. Measurements were replicated every two/four weeks. Results of the trial years were averaged on a seasonal basis. Electrode calibration followed the instruction of Barnant Company (Barrington, IL, USA) using solutions buffered to pH 7 and 4 with Quinhydrone. Redox potentials were measured only during rainy seasons and normalized at pH 7 according to Patrick et al. (1996).

Water table occurrence was monitored with piezometers in four experimental fields (profiles 7, 9, 10, and 11), and inside auger holes in the other soils, with the same observation periodicity.

For micromorphological characterization, three thin sections (55x85 mm) of undisturbed samples for soil horizon were analyzed. IMAGE PRO-PLUS software produced by Media Cybernetics (Silver Spring, MD, USA) calculated pore structure features from digital images of the thin sections, using the approach described by Pagliai et al. (1984). Total porosity and pore distribution were measured according to pore shape and size, the instrument being set to measure pores larger than 50 μm . Pore shape was expressed as $\text{perimeter}^2/(4\pi \text{ area})$, and pores were divided into regular (shape factor 1-2), irregular (2-5) and elongated pores (>5). Pores of each shape group were further subdivided into size classes according to either the equivalent pore diameter for regular and irregular pores, or to the width for elongated pores (Pagliai, 1988). According to their sample position, thin section analysis results were elaborated considering two functional layers: 0.1-0.3 m (layer 1) and 0.4-0.7 m (layer 2). Stony soils, namely profiles 1, 2, 3, and 4, were only sampled in layer 1.

The bulk of data was submitted to Principal Component Analysis (PCA) test by means of the software Statistica (StatSoft Inc., Tulsa, OK, USA).

Results and discussion

During the monitoring period, profiles 7, 8, 9, 10 and 11 showed moisture condition near or above field capacity, and redox potential values low enough to cause the vanishing of oxygen and nitrate, as well as Mn^{2+} formation, when soil temperature at 0.5 m was higher than 6-8°C.

The first step in the statistical analysis was the computing of a correlation matrix for all variables. Selecting from the variables that had been found significantly correlated to at least one other independent variable, we chose the most relevant ones (Table 1), that is, total regular, irregular and elongated macropores; seasonal mean redox potentials and mean water contents; bulk density; clay content; organic matter content; estimated percentage of mottles and permeability of the layer. Other significant variables, such as field capacity and wilting point, were omitted from the successive steps, because they were closely related to clay content.

Results of PCA are reported in figure 1. The two factors explain most part of the total variance (about 71.5%), and they are both related to soil properties affecting soil water holding capacity and to morphological consequences of waterlogging, which contrast with variables associated to aeration. The first factor (or “poor drainage factor”) is highlighted by the variables total regular macropores, clay, permeability class, spring, summer, autumn, and winter soil water contents, which contrast against autumn and winter mean redox potentials. The quantity of regular pores, which are less efficient for downward water transmission (Pagliai and Vignozzi, 2002; Pellegrini et al., 2000), was correlated to an high clay content, an high average soil water content, to lower mean

redox potentials and to higher values of permeability class as evaluated during soil survey (higher values correspond to lower permeability). The second factor (or “good drainage factor”) associated the abundance of elongated and irregular macropores, which favor the water drainage, and of higher soil organic matter content, having a positive effect on soil structural quality, to the other variables pointing to a good drainage, namely lower values of permeability class, scarceness of redoximorphic features (mottles) and lower bulk density.

Conclusions

The study demonstrated that micromorphological analysis could refine the characterization of soil water regime through a quantitative approach. Even if this technique is time consuming and costly, micromorphometric analysis could be used to improve the hydrologic characterization of selected benchmark soils. Further research is needed both to increase experimental datasets and to test the possibility of using micromorphometric data to develop functions for a quantitative estimation of interpretative soil qualities such as permeability class or internal drainage.

Table 1. Main physical, hydrological and chemical soil characteristics¹.

Farm	Profile	Layer	CLAY (g kg ⁻¹)	PERM ²	BD (g cm ⁻³)	O.M. (g kg ⁻¹)	REG (%)	IRREG (%)	ELONG (%)	MOTTLES (%)	aut_REDOX (mV)	win_REDOX (mV)	spr_MOIST (g g ⁻¹)	sum_MOIST (g g ⁻¹)	aut_MOIST (g g ⁻¹)	win_MOIST (g g ⁻¹)
Le Fonti	1	1	233	3	1.49	6.3	0.98	2.25	1.82	0	278	341	0,11	0,08	0,14	0,15
Le Fonti	3	1	236	3	1.46	10.5	0.82	6.55	9.62	0	304	338	0,13	0,10	0,16	0,17
Barbi	4	1	353	3	1.33	4.5	0.68	2.56	3.89	0	279	285	0,14	0,13	0,18	0,20
		2	354	3	1.51	4.0	0.77	2.92	2.93	0			0,14	0,13	0,17	0,20
S. Angelo	5	1	437	3	1.26	16.4	1.01	3.09	4.93	0	269	349	0,15	0,14	0,19	0,20
		2	453	3	1.47	10.2	1.04	2.88	6.28	1			0,18	0,15	0,20	0,20
Trecciano	7	1	389	3	1.56	21.2	1.63	1.92	1.48		245	269	0,17	0,15	0,20	0,21
		2	460	4	1.42	8.6	1.21	1.45	0.55	0			0,20	0,16	0,20	0,21
Modanella	8	1	282	4	1.63	2.1	1.09	2.26	2.86	25	273	285	0,13	0,11	0,17	0,18
Campriano	9	1	423	5	1.65	14.7	1.58	2.48	2.48	5	235	295	0,17	0,12	0,22	0,22
		2	476	5	1.78	2.7	0.93	0.86	0.19	10			0,19	0,13	0,20	0,23
Campriano	10	1	226	4	1.59	5.0	0.85	0.88	0.07	15	313	304	0,13	0,08	0,16	0,17
		2	187	4	1.52	6.6	0.76	0.65	0.07	23			0,14	0,09	0,15	0,17
Cetona	11	1	286	4	1.45	11.3	1.89	1.67	0.83	5	281	294	0,18	0,14	0,22	0,24
		2	257	4	1.56	6.4	0.62	1.27	0.47	8			0,20	0,13	0,21	0,23

¹ MOTTLES stands for percentage of redoximorphic mottles of the layer in macromorphological description, PERM for class of permeability in soil survey, BD for bulk density, aut_REDOX and win_REDOX for mean autumn and winter redox potentials, REG for total regular macropores, IRREG for total irregular macropores, ELONG for total elongated macropores, spr_MOIS, sum_MOIS, aut_MOIS, and win_MOIS for spring, summer, autumn, and winter mean soil water contents.

²3: moderately high (10-1 $\mu\text{m s}^{-1}$). Strong very coarse blocky or prismatic and no stress surfaces or slickensides. ≥ 35 percent clay, soft, slightly hard, very friable or friable. 4: moderately low (1-0.1 $\mu\text{m s}^{-1}$). Few stress surfaces and/or slickensides. 5: low (0.01-0.1 $\mu\text{m s}^{-1}$). Common or many stress surfaces and/or slickensides. (Soil Survey Staff, 2001).

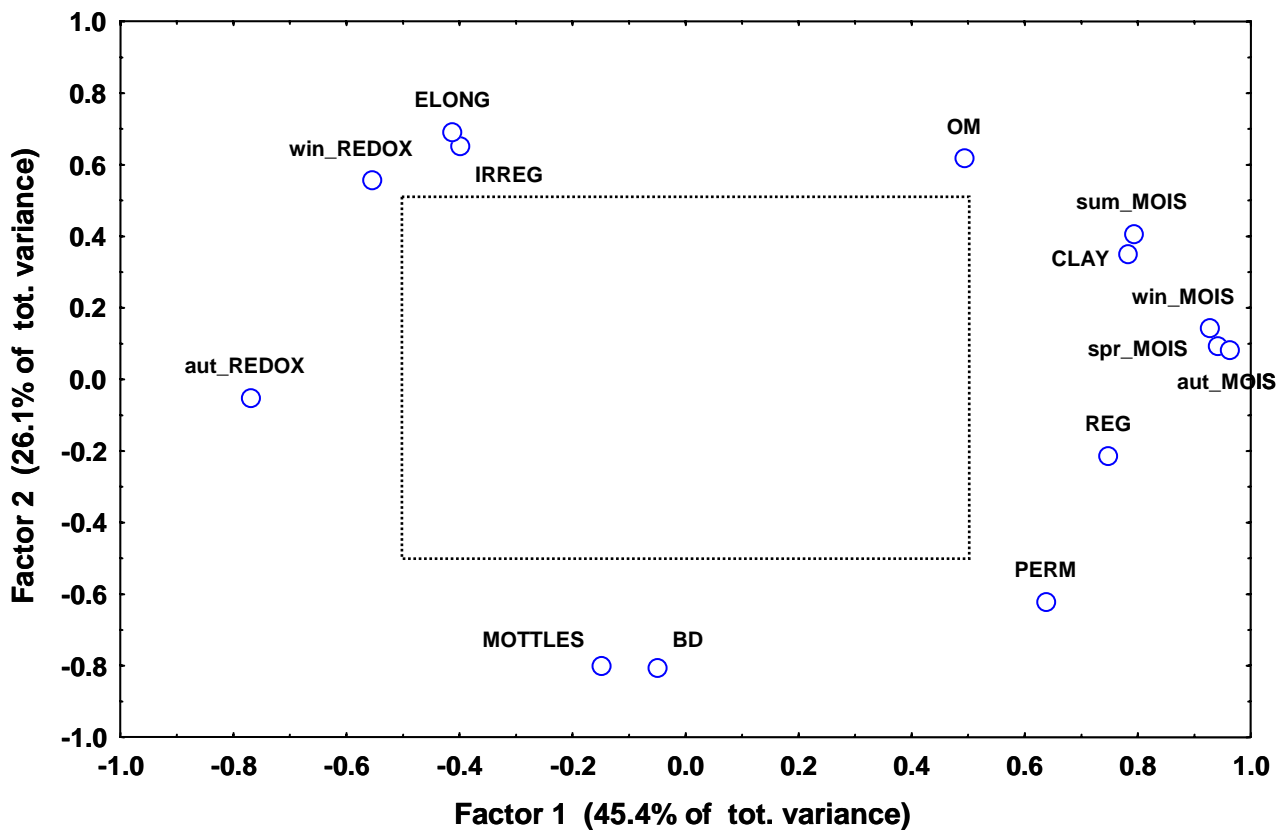


Fig. 1. Results of the PCA: plot of factor loadings.

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