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Relevance of use-invariant soil properties to assess soil quality of vulnerable ecosystems: The case of Mediterranean vineyards

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ABSTRACT

Vineyard landscapes in Mediterranean areas represent a strong cultural legacy and support a crucial socio-economic sector. The sustainability of these landscapes is threatened by rapid changes of soil quality, in the context of global change and intensive management practices. Considering the Languedoc-Roussillon region of southern France as representative of Mediterranean soil and climate conditions, we evaluated the topsoil quality of vineyards at the regional scale, based on a set of 31 physical, chemical and biological soil indicators measured on 164 commercial vineyard plots. Almost all soil parameters were highly variable among plots. Biological activity was low but no systematic perturbation of the trophic web was noticed. The regional variability of use-invariant soil properties (such as calcium carbonate content and texture) was characterized and taken into account for the analysis of dynamic indicators. Invariant soil properties explained up to 25% of the variance of dynamic chemical and biological indicators. Consequently as a tool to improve soil management decision and recommendations, we proposed a grouping of the 164 vineyard plots into functional soil groups determined by soil invariant properties. Information redundancy between different dynamic indicators was analyzed, and their interpretation and limitations as indicators of topsoil quality were discussed. Our study has produced detailed topsoil indicator baselines that can be immediately used as references for winegrowers to appraise the topsoil quality of their vineyard in comparison with others.

1. Introduction

Vineyards deliver environmental, social and economic services to humankind. Since the classical or probably even the Neolithic era, grape vines have been cultivated in Europe. Landscapes of outstanding beauty such as Alto Douro, Lavaux or Saint-Emilion are world heritage sites listed by UNESCO and should be considered as a legacy of past generations. All over the world where grape vines are grown, they are associated with the concept of *terroir*. The *terroir* is defined as a unique ecosystem in a given place including soil, climate and the vine (Van Leeuwen et al., 2004). The *terroir* concept also embraces wine-growing and wine-making practices (Van Leeuwen and Seguin, 2006). Grape vines are grown in patches across the Mediterranean biome, in geographically distinct regions around the world: Europe (France, Portugal, Spain, Italy, Greece), North America (California) and South America, but also Australia and South Africa (Jones et al., 2005) and are often located on soils unsuitable for other crops. Winegrowers commonly practice chemical weeding, tillage, green pruning and intensive pesticide application in order to control yields and to obtain high quality grapes. There are side effects to these practices that can deteriorate soil functioning as they promote soil erosion, soil organic matter depletion, pollution and losses of biodiversity (Coulouma et al., 2006; Hildebrandt et al., 2008; Komarek et al., 2010; Lagacherie et al. (2006) Martinez-Casasnovas et al., 2009; Michaud et al., 2007; Nascimbene et al., 2012; Raclot et al., 2009). Vineyard soil functioning and associated ecosystem services are therefore threatened, especially in vulnerable areas such as

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Mediterranean climatic regions (Schroter et al., 2005), yet they are still poorly documented. Another factor affecting vineyard soils is the recent boom of conversions to organic management practices, but studies on the consequences of such changes on soil functioning are scarce and often assigned to a limited geographical area (Coll et al., 2011, 2012a). A comprehensive understanding of vineyard soil functioning in different *terroir* contexts and under the effect of changes in climate and viticulture practices is needed, and can be approached through the assessment of soil quality.

Soil quality is defined as the ability of soil to function as a vital living system and to deliver ecosystem services related to plant and animal production, regulation of nutrient cycles and pollution and conservation of biodiversity (Doran and Parkin, 1994; Doran and Zeiss, 2000; Karlen et al., 1997; Kibblewhite et al., 2008). Soil quality is evaluated for a specific land use and final user (Arshad and Martin, 2002). In practice, two different types of soil quality are distinguished (Karlen et al., 1997; Wienhold et al., 2004): (i) inherent (or use-invariant) soil quality and (ii) dynamic soil quality. The former is intimately linked to pedogenetic processes; it is almost invariant at the human scale and can be used for land-use planning. In contrast, dynamic soil quality is influenced by land use, agricultural practices, soil management and climate change and is consequently likely to vary over a short time period, especially for the topsoil, i.e. the upper soil layer (0–15 to 0–30 cm). These two types of soil quality are based on specific measurable parameters. Inherent soil quality parameters mainly include stoniness, particle size, soil depth and calcium carbonate contents. For dynamic soil quality stakeholders typically use chemical or physical parameters to evaluate total or available nutrient or water contents, levels of pollutants and risk of erosion. However, biological parameters have recently emerged as indicators able to provide a broader picture of soil quality due to their better sensitivity to environmental changes (Bastida et al., 2008; Fränzle, 2006). Potential biological indicators are numerous. Among them, microorganisms (mainly bacteria and fungi) and nematodes are particularly relevant for large-scale soil quality studies (Schloter et al., 2003) and are known to be particularly active in the topsoil. Soil nematodes are present in all soil types, occupying all trophic levels, and they are directly involved in the cycles of nutrients such as N and P (Irshad et al., 2011). In addition, indices based on the relative abundance of nematode functional guilds (combination of trophic group and life strategy) have been related to farming practices or land use (Bongers, 1990; Ferris et al., 2001; Villenave et al., 2001; Zhang et al., 2012). Microbial biomass, soil respiration, metabolic quotient, and the ratio of organic carbon from microbial biomass to total soil organic carbon are commonly recognized as indicators of the effects of agricultural practices or land use on soil quality (Bastida et al., 2008; Kaschuk et al., 2011; Mader et al., 2002; Probst et al., 2008).

The measurement and analysis of a spectrum of physical, chemical and biological indicators can thus provide a much-needed holistic understanding of soil quality in the particular context of Mediterranean vineyards. The appropriate scale for such a study is the regional scale, at which the wine-growing socio-economic sector is structured and which encompasses the field of action of a number of producer, consultant and commercial organizations. A regional scale evaluation provides a general assessment of soil quality for the whole region, while it also offers a framework allowing finer analyses for specific situations. This issue is particularly important for winegrowers who require management advice tailored to their *terroir* specificities. Contextualized soil management recommendations have as yet been made difficult by the inexistence of a complete and representative set of reference values for dynamic soil properties. The range of variation of dynamic soil properties can be partly determined by inherent soil properties (Dequiedt et al., 2009; Rutgers et al., 2008), and if this correlation is characterized and quantified it can help to produce easily consulted tables of reference values of dynamic properties for different soil types.

To attain these objectives we established an extensive network of 164 commercial Mediterranean vineyards in Southern France, covering a diversity of soils and management practices, on which we measured a large number of inherent and dynamic topsoil parameters. We deliberately promoted biological indicators in our study as (i) these indicators are not frequently used by wine growers in spite of their ability to provide important information on soil functioning and because (ii) physical indicators related to erosion processes (aggregate stability) or soil compaction have already been widely studied in Languedoc Roussillon vineyards and reference values are already available (see publications by Le Bissonnais et al., 2007; Raclot et al., 2009 or Coulouma et al., 2006 and Lagacherie et al., 2006).

We specifically aimed to: (i) produce an evaluation of the soil quality of Mediterranean vineyards through the analysis of a number of inherent and dynamic topsoil parameters, with emphasis on rarely studied biological parameters, and to (ii) quantify the contribution of inherent soil properties to dynamic soil quality in order finally to (iii) propose an operational classification of soils allowing the appraisal by winegrowers of their soil quality in a range of specific *terroir* contexts.

2. Materials and methods

2.1. Study sites and sampling procedures

Nine areas representative of the main wine-growing landscapes found in the Languedoc-Roussillon region were defined, as equivalents of the ecological zones proposed by Arshad and Martin (2002) to be relevant units for soil quality monitoring. The areas were delimited based on expert knowledge of regional geology, geomorphology and vegetation cover (Fig. 1). Within each representative area, plots were selected to cover the diversity of vineyard practices and included both organic and conventional vineyards. Altogether, 164 commercial vineyard plots were sampled as follows in the different representative areas: 18 plots in Aigues-Mortes (Ai-Mortes); 21 plots in Faugères (Faug); 19 plots in Jonquières-Saint-Vincent (J-St-V); 19 plots in Lesquerde (Lesq), 21 plots in Montagnac (Mont); 15 plots in Saint-Hippolyte-du-Fort (St-H-du-F); 23 plots in Saint-Victor-la-Coste (St-V-la-C); 11 plots in Terrats (Terrats) and 17 plots in Vergèze (Verg). The surface area of the studied plots ranged from 0.2 to 2 ha.

The climate in the Languedoc-Roussillon region is typically Mediterranean, with a mean annual temperature of $14.7 \pm 0.6\,^{\circ}C$ and a mean annual rainfall of 694 ± 58 mm (averages based on data collected from 2000 to 2010 by Météo-France in nine weather stations representative of the studied areas). Soils were sampled between March 5 and May 22, 2009, with no more than 2 consecutive days of sampling for each area. For each of the 164 plots, ten topsoil sub-samples were taken randomly in the vineyard from 0 to 15 cm layer at the center of the inter-row, using a gouge auger. Sub-samples were carefully homogenized to form a single representative composite topsoil sample per plot.

2.2. Soil analyses

Thirty-one parameters were analyzed: 7 inherent physical parameters, 8 dynamic chemical parameters and 16 dynamic biological parameters (Table 1). We decided to include pH in dynamic parameters because soil pH evolves during the transformation and cycling of carbon and nitrogen, both influenced by vineyard management (Bolan and Hedley, 2003), and because liming practices can result in significant changes in soil pH.