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The soil quality concept as a framework to assess management practices in vulnerable agroecosystems: A case study in Mediterranean vineyards

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ABSTRACT

Land management aiming to sustain ecosystem services is an important issue, especially in biodiversity hot spots such as found in Mediterranean areas. In Mediterranean areas, viticulture is an important land use. Vineyards are frequently found on inherently poor soils and are submitted to intensive management practices, which threaten soil functioning and associated ecosystem services. To encourage winegrowers and stakeholders to be reflective and adapt their vineyard practices, we evaluated the effects of three soil management practices (inter row plant cover duration, weeding and fertilization strategies) on soil functioning in 146 commercial plots distributed in Southern France, by a complementary set of biological and physico-chemical indicators. We used the concept of soil dynamic quality to evaluate some soil management practices on soil functioning. The influence of inherent soil properties derived from pedogenesis on soil dynamic indicator response was accounted for by considering the response of soil indicators for three soil groups differing in their stoniness and Ca carbonate content. The three soil management practices systematically influenced some nematode-based indicators, whereas other indicators were ascribable to a specific soil type or practice. We demonstrated that the potential of soil management practices to enhance soil functioning is restricted by soil type. In particular for calcareous soils, the soil functioning is very stable limiting effects of soil management practices. The presence of a cover crop, even temporary, in the inter row, is the only practice which benefits soil functioning whatever the soil type whereas organic fertilization and chemical weeding exhibit contrasting results on soil functioning.

1. Introduction

Viticulture is an important economic activity and a cultural legacy in many Mediterranean regions around the world (Jones et al., 2005). Ecosystem services provided by Mediterranean vineyards are particularly threatened, because soil functions are often impaired by yearly-repeated intensive agricultural practices for vine vigour control or weed and pest management. Soil erosion, soil organic matter (SOM) depletion, compaction, pollution, and loss of biodiversity are regularly cited in the literature (Chaignon et al., 2003; Chopin et al., 2008; Coulouma et al., 2006; Komarek et al., 2010; Le Bissonnais et al., 2007; Martinez-Casasnovas et al., 2009; Raclot et al., 2009, Polge de Combret-Champart et al., 2013). Moreover, the Mediterranean climate is characterized by severe summer drought with violent storms promoting soil degradation (González-Hidalgo et al., 2007; Ruiz-Colmenero et al., 2011), erosion and run-off to surface waters. The boom of organic viticulture (Stolz and Schmid, 2007; Schmid et al., 2011) and more generally the increased demand for wine products with a smaller environmental footprint (e.g. reduced loss of nutrients, lower net greenhouse gas emissions, less energy use and pollution), underscore the need to enhance soil organic matter (SOM) content and consequently

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ecosystem services. The concept of soil quality, defined by Doran and Parkin (1994) as “the ability of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health”, is central in the notion of ecological intensification to achieve sustainable yields (Cassman, 1999). It is nowadays commonly used in response to concerns about the contribution of soil functioning to ecosystem services (Bispo et al., 2011). Two different aspects 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 and associated soil types and climates, whereas the latter refers to agricultural practices affecting soil functioning and applies to the surface layer (the first 0–30 cm of soil (Karlen et al., 2003)). Both aspects can be estimated by measurable physico-chemical and biological indicators (Salome et al., 2014).

Vineyard management includes diverse agricultural practices, which all affect soil functioning. Mechanical weeding, for instance, can decrease the soil organic carbon (SOC) content (Mazzoncini et al., 2011; Six et al., 1999), induce physical degradation of vineyard soils (Coulouma et al., 2006), or modify soil biological communities at different trophic levels (Sanchez-Moreno et al., 2006; Schreck et al., 2012). Conversely, soil amendment or organic fertilization improves soil structure and SOM content (Pérès et al., 1998; Navel and Martins, 2014), with contrasting results depending on both quantity, and quality of the organic matter applied (Navel and Martins, 2014). Plant cover in vineyards contributes to essential services such as water infiltration, carbon sequestration, nutrient supply and retention, and reduction of soil erosion (Mazzoncini et al., 2011; Peregrina et al., 2010; Ruiz-Colmenero et al., 2013; Smith et al., 2008; Steenwerth and Belina, 2008b). Wine growers in Mediterranean regions are nevertheless reluctant to use cover crops, due to concerns about water competition between cover crops and grapevines (Celette et al., 2009; Celette and Gary, 2013; Tesic et al., 2007) even if in the last years the use of intercropping has increased in Mediterranean vineyards (Mercenaro et al., 2014). Trade-offs between competition for resources and services provided by cover crops have to be reduced (Ruiz-Colmenero et al., 2011) through adapted cover crop management. Dynamic soil quality monitoring, using responsive indicators adapted to the local soil type and climate, could help to fine-tune management practices aiming to optimize soil functioning. Soil quality monitoring is a promising component of innovative and flexible soil management strategies that would respond to the complexity of vineyard soils and practices combined with climatic constraints (Ripoche et al., 2010). Recent developments in soil biology and ecology contribute to the evaluation of soil quality, as they offer new and complementary dynamic indicators to the classical, chemical indicators of soil functioning (Coll et al., 2011; Probst et al., 2008; Steenwerth and Belina, 2008a; Virto et al., 2012; Salome et al., 2014).

While land management is reasoned at the landscape or farm level (Herrick, 2000), most soil quality evaluations are point-based, which reduces their usefulness for land management. Winegrowers have the additional concern of tailoring their land management to the specificities of their *Terroir* (Van Leeuwen et al., 2004), which are partly based on inherent soil quality derived from pedogenesis.

The objective of our study was to evaluate the influence of soil management practices on soil quality in Languedoc-Roussillon vineyards of Southern France, in order to encourage winegrowers to be reflective and adapt their own practices to achieve environmental, social and economic sustainability. The soil quality concept is a useful framework to discuss soil management practices in the context of agroecological paradigms. In a previous study in the same region, Salome et al. (2014) measured the values of 23 soil indicators on a large number of vineyard plots, in order to produce a precise and comprehensive reference dataset of soil dynamic quality. The mean value and range of these indicators were presented for the different soil groups found in the studied region. In the present study, we focused on the effects of farming practices according to soil groups. We selected the three practices that were most commonly cited by surveyed winegrowers, and for which strongly contrasting strategies were observed: (i) inter-row plant cover, which could be inexistent, temporary or permanent; (ii) weeding, which could be chemical, mechanical or replaced by mowing; and (iii) fertilization, which could be based on organic or mineral compounds. We thereafter considered these strategies as different proxies of soil perturbation intensity like in Cluzeau et al. (2012). Finally, we analyzed the response of 23 physical, chemical and biological indicators of dynamic soil quality to these management options, in 146 vineyard soils clustered into three soil groups according to their inherent soil quality.

2. Materials and methods

2.1. Localization and sampling

In a previous study, Salome et al. (2014) described 164 vineyard plots representative of the heterogeneity of landscapes and management practices in the Languedoc Roussillon region (France), which were sampled between March and May 2009. We encourage readers to refer to Salome et al. (2014, Fig. 1) for a map with details of studied areas. We ensured from winegrowers that all plots were conducted with the same management during the 5 years preceding the sampling year. None of the selected plots were irrigated. The initial dataset of Salome et al. (2014) is reduced to 146 plots for the present study. Indeed, the 18 plots from the Aigues Mortes zone (43°36′27″N, 2°46′14″E, Arenosols, WRB soil classification) included in the dataset of Salome et al. (2014) were not selected in the present study because management practices were specifically adapted to this particular soil type (with saline, alkaline and sandy soils) and therefore insufficiently contrasted in terms of practices. In the present study, the 146 selected vineyard plots are located around the towns of Jonquière Saint Vincent (43°49′38″N, 4°33′48″E, mainly Red Grenache and Syrah with double Royat cordon trellising, and Rhodic Luvisol), Montagnac (43°28′50″N, 3°29′02″E, a variety of cultivars, dominated by White Picpoul and Red Syrah with double Royat cordon vine training, Calcisols), Faugères (43°33′57″N, 3°11′19″E, mainly Red Grenache, Syrah and Carignan with Gobelet and double Royat cordon, Cambisols), Lesquerde (42°48′01″N, 2°31′47″E, mainly Red Syrah and Carignan with a dominance of Gobelet, double Royat cordon and simple Guyot, Arenosols), Saint-Hippolyte-du-Fort (43°57′56″N, 3°51′28″E, mainly Red Grenache conducted with double Royat cordon, Calcisols), Saint-Victor-la-Coste (44°03′38″N, 4°38′29″E, mainly Red Syrah, Carignan and Cinsault with exclusively double Royat cordon, Calcisols), Terrats (42°36′27″N, 2°46′14″E, a variety of cultivars with a dominance of White Muscat and exclusively Gobelet and double Royat cordon, Luvisols and Cambisols) and Vergèze (43°44′37″N, 4°13′14″E, mainly Red Cabernet Sauvignon and to a lesser extent Merlot with a majority of double Royat cordon, Cambisols). The 146 plots were assigned to 3 main soil groups (A, B, C), defined on the basis of their Ca carbonate and stone contents, in order to take into account the influence of the most determining inherent soil properties on soil dynamic indicators, identified in Salome et al. (2014) i.e. Ca carbonate content, stoniness and texture. Group A includes all non-stony calcareous soils in the fine or medium FAO textural class (sub-classified according to texture as groups 2 and 3 in Salome et al., 2014); Group B corresponds to non-stony and non-calcareous soils characterized by the medium or coarse FAO textural class (sub-classified as groups 4 and 5 in