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Review

Management of service crops for the provision of ecosystem services in vineyards: A review

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ABSTRACT

Service crops are crops grown with the aim of providing non-marketed ecosystem services, i.e. differing from food, fiber and fuel production. Vineyard soils face various agronomic issues such as poor organic carbon levels, erosion, fertility losses, and numerous studies have highlighted the ability of service crops to address these issues. In addition to their ability to increase soil organic matter and fertility, and reduce runoff and erosion processes, service crops provide a large variety of ecosystem services in vineyards such as weed control, pest and disease regulation, water supply, water purification, improvement of field trafficability and maintenance of soil biodiversity. However, associating service crops with grapevines may also generate disservices and impair grape production: competition for soil resources with the grapevine is often highlighted to reject such association. Consequently, vinegrowers have to find a balance between services and disservices, depending on local soil and climate conditions, on their objectives of grape production and on the nature and temporality of the ecosystem services they expect during the grapevine cycle. This study proposes a review of the services and disservices provided by service crops in vineyards, and a framework for their management. Vinegrowers' production objectives and pedoclimatic constraints form the preliminary stage to consider before defining a strategy of service crop management. This strategy assembles management options such as the choice of species, its spatial distribution within the vineyard, the timing of its installation, maintenance and destruction. These management options, defined for both annual and long-term time scales, form action levers which may impact cropping system functioning. Finally, we underline the importance of implementing an adaptive strategy at the seasonal time scale. Such tactical management allows adapting the cropping system to observed climate and state of the biophysical system during the grapevine cycle, in order to provide targeted services and achieve satisfactory production objectives.

1. Introduction

Viticulture is one of the most erosion-prone land uses (García-Ruiz, 2010): soils often present poor organic carbon levels (Coll et al., 2011; Salomé et al., 2016), some vineyards are located on steep slopes and shallow soils where heavy rain events generate runoff, and soil tillage exacerbates soil losses (Le Bissonnais and Andrieux, 2007). Such degradation of soil quality may bring serious problem for wine production as soil represents a key component of the concept of terroir (van Leeuwen et al., 2004). Thus, protection of soils is a major issue in viticulture.

In a recent regional survey, the adoption of cover crops in Mediterranean vineyards relied on expected improvements in biodiversity, soil organic matter (SOM), erosion control and trafficability (Frey, 2016). This survey highlighted how the practice of cover cropping may provide solutions to a large number of issues in viticulture. However, it was not systematically adopted depending on the technical and pedoclimatic context and the related risk of competition for soil resources. Indeed, 49% of French vineyards were cover cropped in 2010, permanently (39%) or not, over all (11%) or part of their surface

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area (Ambiaud, 2012). Strong discrepancies among regions were observed, some (e.g. Alsace, Bordeaux) being more than 85% cover cropped, others (e.g. Champagne, Provence, Languedoc) being less than 30% cover cropped. Low cover cropping would be due in Champagne to technical constraints (narrow inter-rows) and high yield objectives and in Mediterranean regions to limited soil water resources. Yet the high variability of practices among grape growers in the same region also reveals uncertainties about the proper way of managing cover crops to fulfill a set of production and environmental objectives.

In the literature, cover cropping has been extensively assessed in a variety of soil and climate conditions across the world, largely under Mediterranean climate: South Africa (e.g. Fourie, 2012; Fourie et al., 2001), Australia (e.g. Dinatale et al., 2005; Quader et al., 2001), California (e.g. Baumgartner et al., 2008; Ingels et al., 2005; Steenwerth and Belina, 2008a,b), Italy (e.g. Ferrero et al., 2005; Pardini et al., 2002), Spain (e.g. Gago et al., 2007; Marques et al., 2010; Ruiz-Colmenero et al., 2011), Chile (e.g. Ovalle et al., 2007), France (e.g. Celette et al., 2008; Gaudin et al., 2010; Ripoche et al., 2010; Schreck et al., 2012). Beyond soil protection, these studies identify a large variety of ecosystem services provided by cover crops in vineyards, such as weed control, pest and disease regulation, water supply, water purification, field trafficability, soil biodiversity and carbon sequestration.

Daily (1997) defined ecosystem services (ES) as the "conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life". Cultivated farmland is a specific ecosystem with the main objective of providing food, fiber and fuel (Swinton et al., 2007). While supporting and regulating ES generally promote food production, some ecosystem disservices (EDS) tend to hinder it. Competition for soil resources (e.g. water and nitrogen) is a good example of cover crop disservice (Celette and Gary, 2013; Ruiz-Colmenero et al., 2011). Cover crops can achieve provisioning, supporting and regulating functions (e.g. food production, improvement of soil fertility and physical features, water availability, diseases, pests and weeds control), but can also provide more environmental and cultural benefits (e.g. water purification, carbon sequestration, biodiversity conservation and landscape aesthetics). Agriculture sits at the interface of ES and EDS as it both provides and receives services and disservices: managing agricultural ecosystems means "optimizing the flows of ES and EDS to and from agriculture" (Zhang et al., 2007).

Cover crops need to be properly managed to provide services while avoiding disservices. As the knowledge of cover crop species and their suitable management may be long to master and because this practice also involves supplementary costs and long-term economic returns, vinegrowers may be discouraged to adopt it (Dunn et al., 2016). Methods for evaluating the achievement of services in cropping systems, and for designing agroecosystems providing targeted services have recently been proposed in the scientific literature (Gaba et al., 2015; Rapidel et al., 2015; Schipanski et al., 2014). ES management has to be driven through various action levers i.e. management options that impact cropping system at both short and long-term time scales. Composition (e.g. crop species and varieties) and structure of cropping systems (e.g. spatial arrangement, rotations) may lead to different sets of potential services achieved by agroecosystems. Several methods of selection of species according to targeted services have been proposed, such as multicriteria decision analysis (Ramírez-García et al., 2015), or trait-based approaches (Damour et al., 2015; Tardy et al., 2015). Sowing densities, strip arrangements, field architecture, plant diversity are other management options that can impact potential services (Gaba et al., 2015). Tactical decisions (e.g. mowing, irrigation or fertilization) also participate in driving ES and EDS. Tactical decisions concern technical operations at seasonal time scale, depending on climate and state of the biophysical system during the crop(s) cycle(s). Flexibility and adaptive management are recognized to be relevant to reach an adequate balance between ES and EDS (Ripoche et al., 2011b, 2010). ES are time-dependant, as some services accumulate gradually while others integrate over long time periods (Schipanski et al., 2014). Schipanski et al. (2014) also underscored the time-sensitivity of field management, introducing a management risk proxy in their analysis, e.g. risk of crop yield loss or failure of cover crops to establish. Thus, temporality of services should be taken into account when analysing and evaluating ES provision in cropping systems.

We will now use the term "service crops" in reference to grapevine associated crops. This is to emphasize the purpose of such a crop but also the importance of considering these plant communities as another crop that needs to be managed.

The principal objective of this paper is to produce a framework for the management of service crops in vineyards for wine grape production. To build such a framework, we first identify the major ES and EDS documented for service crops in vineyards and the main associated biophysical functions. Then, we discuss the balance between ES and EDS and we highlight the dependency of the provision of ES on the context and the management levers vinegrowers can use to promote them. We conclude with our framework proposal which relies on all previous analyses made along the paper.

2. Services and disservices of service crops in vineyards

ES and EDS provided by service crops in vineyards can be classified into two categories. Input services and disservices are provided by service crops to vineyard, i.e. impacting the agricultural system (upper portion of Fig. 1). Output services and disservices are provided by service crops from vineyard (lower portion of Fig. 1).

2.1. Supporting and regulating services for viticulture

2.1.1. Soil physical properties and water budget

Service crops may protect soil from water and wind erosion in vineyards (Le Bissonnais et al., 2004; Novara et al., 2011). They improve the stability of soil aggregates (Goulet et al., 2004) and protect them from the impacts of rain drops, reducing aggregate breakdown and soil detachment (Dabney et al., 2001). Service crops also prevent soil crusting and sealing (Durán Zuazo and Rodríguez Pleguezuelo, 2008). As an example, a 4-year experiment measuring water erosion in Gerlach troughs under various treatments (tillage, *Secale cereale* and *Brachypodium distachyon* service crops) showed soil loss reductions by 91% and 93% with *Secale* and *Brachypodium*, respectively (Ruiz-Colmenero et al., 2013). The ability of service crops to reduce surface runoff largely depends on the covering rate (Andrieux, 2007).

Moreover, service crops maintain favourable soil structure and porosity in vineyards (Ferrero et al., 2005; Polge de Combret-Champart et al., 2013) as in other cropping systems (Hermawan and Bomke, 1997). As a consequence, service crops improve water infiltration and reserve refilling during the rainy season (Gaudin et al., 2010). This better infiltration is partly linked to the soil surface properties: service crops increase soil surface roughness, and the root system increases soil macroporosity (Leonard and Andrieux, 1998). As a consequence, soil surface hydraulic conductivity is improved (Wassenaar et al., 2005). During rainfall events, when soil is saturating, hydraulic conductivity of soil surface decreases, leading to surface water runoff. However, this decrease in soil hydraulic conductivity appears to be lower in presence of a service crop (Joyce et al., 2002). Water infiltration during rainfall events is also increased because the service crop leaf area reduces the kinetic energy of raindrops and increases the residence time of water at the soil surface (Meisinger et al., 1991; Wassenaar et al., 2005). Finally, soil moisture at field capacity and soil water retention capacity are increased, due to an improved soil structure and a potential increase in soil organic matter (Morlat and Jacquet, 2003).

The ability of service crops to improve rainfall infiltration and enhance soil water storage is particularly interesting in areas where precipitation occurs during winter over a relatively short period of time in a series of heavy rainfall events. Indeed, this additional water may