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 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), 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 Figure 1). Output services and disservices are provided by service crops from vineyard (lower portion of Figure 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

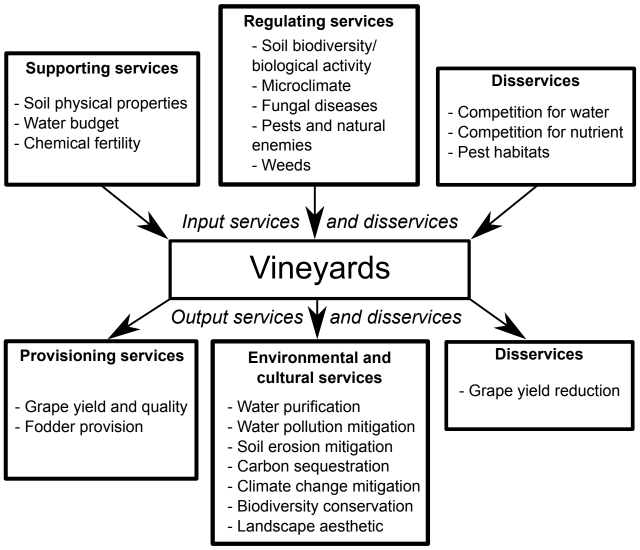

Figure 1: Ecosystem services and disservices expected from service crops in vineyards.

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 benefit the vine during the subsequent year (Gaudin et al., 2010). However, competition may occur as this additional water could be partly or totally transpired by the service crop (Celette et al., 2008; Thorup-Kristensen et al., 2003). In semi-arid conditions with low precipitation during the summer period, competition for water may impair grapevine yield at both year n and year n+1 (Guilpart et al., 2014). In contrast, in overly-wet soils, the water uptake by service crops may enhance soil water extraction and create better conditions for vine growth (Unger and Vigil, 1998). Mulching techniques may also decrease soil evaporation (Unger and Vigil, 1998) and prevent runoff and erosion from vineyard soils (Prosdocimi et al., 2016).

Growing service crops in the inter-row is also known to increase soil resistance to compaction and improve bearing capacity (Ferrero et al., 2005; Polge de Combret-Champart et al., 2013). As a consequence, trafficability in vineyards may be improved. Depending on the grass species and the structure of their root systems, service crops could restore compacted soil (Blanco-Canqui et al., 2015).

2.1.2. Soil chemical fertility

Soil nutrients and organic matter content can be affected by the presence of service crops (Fourie, 2012). Service crop effects differ according to their specific function, i.e the processes changing the ecosystem state or interacting between two components of the ecosystem (Jax, 2005), for example decomposition or nutrient recycling. Service crops provide various services in relation to soil fertility, as nitrogen (N) supply (green manures, i.e. growing plants that are mown or ploughed in order to provide N to the soil), or leaching reduction (catch crops, efficient scavengers of residual soil nitrate (NO3-)) (Thorup-Kristensen et al., 2003). This N taken from the soil is generally made available to the co-occurring or subsequent crop by the destruction of service crops (e.g. mowing, tillage) and their decomposition and mineralization (Patrick et al., 2004). Service crops can be an alternative to chemical N-fertilizer addition and a source of input savings (Hartwig and Ammon, 2002). Competition for nitrogen may occur, as available N can be depleted by service crops during grapevine dormancy, and stuck in an organic form (alive or dead plants) before being released by mineralization (Thorup-Kristensen et al., 2003). It is known that the amount of nitrogen made available for the next or associated crop will depend on the C/N ratio of the service crop (Finney et al., 2016) and the biomass produced (Vrignon-Brenas et al., 2016). Indeed, service crop mixtures including leguminous and non-leguminous species can combine NO3-leaching reduction and green manure services, thus improving N use in cropping systems (Tribouillois et al., 2016).

On the contrary, service crops may also decrease nitrogen availability for grapevines, both directly and indirectly. During growth, service crops may take up and immobilize N, thus becoming unavailable for grapevines. Service crops can also take up soil water so that mineralization and the resulting inorganic N supply for grapevines are reduced in a dry soil (Celette et al. (2009), Figure 2).

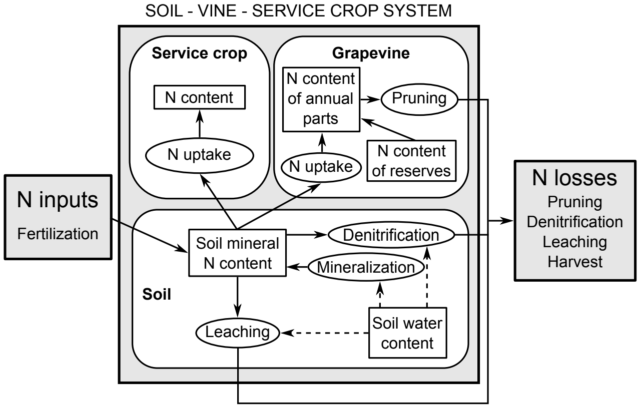

Figure 2: Conceptual model of nitrogen losses during service crop and grapevine growth period (adapted from Guilpart et al. (2011)). The existence of two N uptake arrows from the same soil N content pool suggests the risk of competition.

Little information exists on the effects of service crops concerning the status of other nutrients (Thorup-Kristensen et al., 2003). Uptake of soil phosphorus (P), potassium, and manganese is reported with different legume and non-legume species in greenhouse studies. In the case of annual cropping systems, (Takeda et al., 2009) reported that soil phosphatase activity and microbial P, both representing the potential of P mineralization, were enhanced with rye, whereas rapeseed had minor effects on the soil P parameters. (Ovalle et al., 2007) reported an increase in P and K levels in the soil, for vineyard intercropped with subterranean clover (*Trifolium subterraneum L.*), burr medic (*Medicago polymorpha L.*) and balansa clover (*Trifolium michelianum Savi*) after two years of intercropping. However, Blanco-Canqui et al. (2015) reported that service crops could sometimes decrease available soil P by uptake and conversion into organic form.

2.1.3. Soil biodiversity and biological activity

Service crops impact soil fauna abundance and biodiversity (Coll et al., 2009). Rahman et al. (2009) found that permanent vegetation increases beneficial nematodes, i.e. free-living populations, and tends to decrease plant-parasitic populations. Service crops and reduced soil perturbation provide resources that maintain higher trophic levels in soils (Sánchez-Moreno et al., 2009). Additionally, compared to soil tillage, the introduction of service crops and mulches has a positive impact on earthworm abundance and activity (Coll et al., 2011; Peigné et al., 2009; Vrsic, 2011). Schreck et al. (2012) also underlined that chemical weeding can favour overall earthworms abundance (non-disturbed soil) but may also decrease the number of specific populations (epi-anecic worms) and cause toxic stress, cellular dysfunction or apoptosis for earthworms. They reported that growing service crops in the inter-row seems to be the best environmental practice.

Service crops may also enhance arbuscular mycorrhizas fungi development which can form mutualistic symbiosis with many plants including grapevine (Cheng and Baumgartner, 2006), and may have a positive impact on microbial biomass and soil biological activity (Ingels et al., 2005; Steenwerth and Belina, 2008a,b). Service crops may favour microbial abundance and activity in Cu contaminated soils (common observation in organic vineyards) by enhancing soil organic matter (Mackie et al., 2014). However, in some cases service crops can favour inorganic N immobilization because of microorganism demand (Peregrina et al., 2012; Thorup-Kristensen et al., 2003).

2.1.4. Microclimate and regulation of fungal diseases

At the beginning of spring when temperature is increasing, service crops could maintain relative humidity in the field and canopy, and increase frost risk and damage (Sánchez et al., 2007). This increase in relative humidity inside the canopy can also favour fungal disease development (Valdés-Gómez et al., 2011).

On the contrary, in cases of strong grapevine growth, intercropping service crops can prevent the excessive vegetative and reproductive development of grapevines and increase potential evapotranspiration, reducing in fine fungal development (Guilpart et al., 2017; Valdés-Gómez et al., 2011). In most cases, a reduction in plant growth combined with an increase in plant or crop porosity reduces infection efficiency and spore dispersal (Calonnec et al., 2013). The reduction of vegetative growth also impacts the canopy microclimate, with drier conditions limiting the development of grey mould (Valdés-Gómez et al., 2011). The introduction of service crops may also improve soil biological activity, leading to a faster decomposition of vine residues which are habitats for Botrytis cinerea primary inoculum. (Jacometti et al., 2010) found a correlation between canopy aeration (often enhanced under service crops treatments) and berry skin strength, a source of grape resistance to disease infection. They highlighted that the mulched grass in vineyards was linked to the highest level of berry phenolic compounds, which have antifungal properties.

Finally, during extreme climatic events such as heat waves, service crops and mulches may mitigate soil reflection and thus reduce possible damage to grapes. A survey of Australian vinegrowers allowed these observations (Webb et al., 2010) but documented experiments are lacking concerning the underlying mechanisms.

2.1.5. Regulation of pests and natural enemies

Growing service crops may play a role in the regulation of pests in vineyards as a part of a conservation biological control strategy to protect grapevines (Fiedler et al., 2008). Service crops may introduce plant diversity (e.g. floral strips) into the vineyards that could shelter natural enemies (Liguori et al., 2011; Woltz et al., 2012). Some authors suggest that this role would be improved if selected service crop species are native plants, which cover a larger flowering period than non-native ones (Fiedler et al., 2008). Several mechanisms may explain how a service crop shelters natural enemies. In some cases, microclimate factors are likely to be involved (Bugg and Waddington, 1994). More generally, the availability of alternative foods in the form of floral resources and/or prey or hosts in the non-crop vegetation may have contributed to the observed effects (Landis et al., 2000).

However, other studies indicate inconsistent or limited benefits of such service crops in vineyards on natural enemies (Bugg and Waddington, 1994). Service crops could also shelter grapevine pests and viruses (Hanna et al., 2003), and in some cases increase pest attacks (Wermelinger et al., 1992).

For example, grass cover may act as a host for soil-borne pathogens or nematodes. Castillo et al. (2008) highlighted how weeds may host plant parasitic nematodes which could then contaminate grapevine root systems. Some service crop species (e.g. Vicia sativa) could be good hosts for Root-knot nematodes. Indeed, root-lesion nematodes appeared to prefer perennial service crops and weeds rather than annual service crops which are sown annually or biannually (Quader et al., 2001). Other experiments suggested that plant parasitic nematodes were suppressed by predatory nematodes under service crop treatments, where soils supported better food web structure (Coll et al., 2009). Another mechanism involved in the reduction of pest pressure is the production of allelochemicals by service crops. Some authors suggest selecting Brassica species which are known to have direct deterrent or toxic effects on plant parasitic nematodes (Addison and Fourie, 2008).

2.1.6. Weed control

Several studies highlight the ability of service crops to control weed infestation, particularly during the winter period (Baumgartner et al., 2008). Weed control is a relevant service expected from service crops as weed species could be source of important competition with grapevines for soil resources such as water and nitrogen (Lopes et al., 2004). Service crop management becomes part of the whole management of the agro-ecosystem (Tixier et al., 2011), and could be considered as a non-specific biological method of pre-emergence weed control (Fourie et al., 2001). Moreover, service crops could decrease herbicide use in agriculture as service crops can have weed suppression effects (Tworkoski and Glenn, 2012).

Service crop establishment (seed germination and emergence, juvenile growth) and soil covering rate (competition for light) are important factors that contribute to weed suppression in agrosystems (Miglécz et al., 2015; Tardy et al., 2015). With low soil disturbance, competitive exclusion by the dominant species arises (Townsend et al., 1997). Weed community structure and dynamics can be affected by growing service crops as competitive exclusion should occur on weeds, the service crop being the dominant species. In a Californian vineyard, Steenwerth et al. (2016) observed shifts in weed community composition, comparing tilled and sown plots (oat and a mix oat/legumes). In Mediterranean climate, similar results were found in experiments that compared soil tillage and service crop treatments, with evidences of changes in weed community structure and dynamics (Monteiro and Lopes, 2007), and lower infestation by weeds under sown service crops (Gago et al., 2007). In other cropping systems, weed suppression was positively correlated to service crop biomass (service crop dominance on weeds) and C/N ratio (N retention, decomposition rate) (Finney et al., 2016; Vrignon-Brenas et al., 2016).

Mulch management is essential for weed suppression as it depends both on the features of crop residues and on the targeted weeds to suppress (Ranaivoson et al., 2017). The difficulty is to find a service crop that efficiently competes with winter weeds and produces enough mulch in summer to impede the emergence of summer weeds (Fourie, 2010). Allelochemical compounds released by residue decomposition play a role in weed suppression as they reduce weed seed germination and growth (Lou et al., 2016).

Weed seed predation may increase with vegetation cover (Meiss et al., 2010). Vegetation cover changes the habitat for seed predators: it modifies light and temperature at the soil surface, affects soil characteristics and gives alternative food systems for predators (leaves, larvae). Dead plant material can form substrates for predator reproduction, and service crops may be used as a shelter for seed predators, decreasing the risk of being predated by other animals. Consistent preferences of seed predators for certain weed species indicates that seed predation may be another cause of the observed weed community shifts (Meiss et al., 2010).

2.2. Environmental and cultural services

2.2.1. Mitigation of water pollution and water purification

Service crops potentially increase the nutrient use efficiency of vineyards (Celette et al., 2009; Dabney et al., 2001) and so reduce potential sources of groundwater pollution. Both the amount and timing of N uptake by service crops depend on several factors such as soil and climate conditions, the service crop species and its management (Dabney et al., 2001; Thorup-Kristensen et al., 2003). Nitrate leaching may be reduced with a service crop by the direct uptake of this residual soil nitrogen, but also by decreasing runoff (García-Díaz et al., 2017) and stimulating microbial activity which could promote nitrate immobilization and recycling (Peregrina et al., 2012).

The reduction of surface runoff (García-Díaz et al., 2017) and soil erosion (Raclot et al., 2009), may reduce a source of surface water pollution with suspended solids (organic or not) and pesticides (Alletto et al., 2010). As service crops reduce surface runoff and improve water infiltration, pesticides penetrate better into the soil where they can be degraded. However, associated cropping or mulch practices can increase pesticide leaching when enhancing soil hydraulic conductivity (e.g. macroporosity induced by roots). Moreover, an increase in soil organic matter content in the topsoil layer (as often observed in systems with service crops) may lead to more pesticide retention and fewer molecules available, avoiding their degradation by microorganisms (Alletto et al., 2010). The balance between retention and degradation depends, above all, on soil characteristics and active substance types. Komárek et al. (2010) underlined that a vegetation cover enhances microorganism diversity in soil and supports fungicide degradation, and associated with erosion control, service crops may decrease copper contamination by runoff from vineyards.

2.2.2. Carbon sequestration and mitigation of climate change

As service crops can increase soil organic matter (SOM) in the topsoil layer, they may contribute to carbon sequestration. However, with a permanent service crop, soil organic matter content changes in the topsoil layer only (Fourie, 2012; Ruiz-Colmenero et al., 2011), and this change is generally slow: Celette et al. (2009) observed no significant change of SOM content with a permanent service crop over a four year period, while Morlat and Jacquet (2003) observed a significant increase in SOM in the topsoil layer after 17 years of permanent grass cover. In contrast, some studies highlight significant increase in SOM content, depending on the service crop species, after only three years (Belmonte et al., 2016; Marques et al., 2010). The service crop biomass production also contributes to the sequestration process but could be limited in case of a reduced dry matter production, because of poor soil quality or unfavourable climate condition for example (Celette et al., 2009; Coll et al., 2011; Salomé et al., 2016).

According to Arrouays et al. (2002), a permanent grass cover in vineyards increases carbon storage in soils. Such carbon storage was estimated at $0.49 \pm 0.26 tC/ha/yr$ (20-years projection scenario); other authors later confirmed this range of values (Freibauer et al., 2004). Salomé et al. (2016) found similar results for carbon content under permanent plant cover. Williams et al. (2011) showed that scaling up vine management to landscape level, by maintaining wildlands in mosaic organization with vineyards, could be beneficial for increasing overall C stocks. As for carbon balance, it is important to take into account the global carbon footprint of vineyard cropping systems as mechanized soil tillage and service crop mowing can increase CO2 production from fossil fuels.

Different studies suggest that no-till and service crops lead to an increase in N2O emissions of vineyards soils (Garland et al., 2011; Steenwerth and Belina, 2008b). In no-till situations, the same results were shown, especially in poorly-aerated and compacted soils (Rochette, 2008). In contrast, (Rochette, 2008) showed that no-till practice would not have a negative impact in good aerated soils; thus, a service crop, which favours soil porosity, might counteract the negative impact of no-till practices on N2O emissions. However, these works also highlight that N2O emissions are low in vineyards. These low values could be the consequence of generally low fertilized situations and dry conditions (Garland et al., 2011). Comparisons between N2O-measurement studies should be done with caution, soil texture being a strong driver of N2O emissions through its water content (Yu et al., 2017).

2.2.3. Conservation of biodiversity and wildlife

Service crops could increase the insect biodiversity in specialized vineyard areas where the habitats are less diverse and where insects are mainly represented by crop parasites (Dinatale et al., 2005). For example, some species, e.g. clover species, might be attractive for gophers (Ingels et al., 2005): service crops could therefore enable wildlife conservation in some areas (Smallwood, 1996). Smallwood (1996) found predatory vertebrate species in systems with service crops (this observation was also made by the farmers), which could help controlling vertebrate pest population, keeping their damages to an economically acceptable level. Gurr et al. (2003) underline that lots of birds and small mammals use grassy field margins to live in and find food resources. In biodiversity and conservation corridor research, service crops seem to be the most useful vegetation for providing wildlife food sources over the winter period (Kinross et al., 2002).

2.2.4. Landscape aesthetics

Service crops in vineyards can also improve the aesthetic value of farms and landscapes and attract more visitors (e.g. tourists groups) and might lead to an economic benefit for farmers (Gurr et al., 2003; Smallwood, 1996).

Figure 3: Intercropped vineyard with flowering spontaneous vegetation in south of France (©Hélène Frey).

Some authors estimated the monetary value of ES (Costanza et al., 1997; Porter et al., 2009). Landscape aesthetics, with nitrogen turnover, food and raw material production, form the largest monetary contribution from ES: the aesthetic values of arable farms was estimated at USD 138, 262 and 332.ha-1.year-1 for cereals, pasture and wooded arable landscapes, respectively (Porter et al., 2009). Giving a value to habitat management (biological pest control, wildlife and biodiversity conservation, landscape aesthetics) could give a financial reason to farmers for preserving or restoring natural communities in their farms (Fiedler et al., 2008). Non-market valuation techniques also exist and could be useful to take into account this kind of cultural service in public policy decisions (Swinton et al., 2007).

The interactions between ES provided by habitat management (e.g. landscape aesthetic, biodiversity and wildlife conservation, pest regulation by natural enemies) show the importance of managing vineyards at the landscape level to make service crop practices effective for ES supply (Fiedler et al., 2008; Kinross et al., 2002; Landis et al., 2000).

3. A FRAMEWORK TO HANDLE THE COMPLEXITY OF MANAGING SERVICE CROPS: SERVICES VS. DISSERVICES, CONTEXT AND TIMING

3.1. Managing the balance between services and disservices

3.1.1. Managing support services: the example of soil water and nitrogen availability

Managing the balance between grape yield and berry quality is of particular importance in wine production. Both excessive water availability and severe water stress can alter berry development and the resulting wine quality. On the one hand, grapevine should experience a moderate water stress after the flowering stage to limit grapevine vegetative development and control the formation of grape yield and quality (Deloire et al., 2004; Gaudin et al., 2014; Pellegrino et al., 2006). On the other hand, over intense water stress may jeopardize grape yield at year n but also at year n+1 (Fourie, 2011; Guilpart et al., 2014). Consequently, depending on the objective of grape yield and quality, a specific time-course of low to moderate water stress can be defined. Pellegrino et al. (2006) suggested optimal classes of FTSW (Fraction of Transpirable Soil Water, a water stress indicator) from budburst to harvest for the management of premium red wine production, considering water stress effects on vine growth and berry production (Figure 4). Other authors suggest that a moderate water stress, managed with deficit irrigation or partial rootzone drying, may improve berry quality (dos Santos et al., 2007; Lopes et al., 2011).

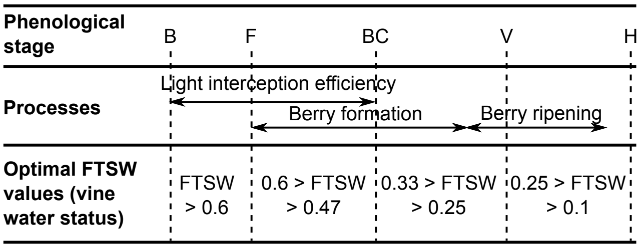

Figure 4: Optimal change over time of the classes of the indicator of vine water status FTSW (Fraction of Transpirable Soil Water) for a premium red wine production. The main processes characterizing the phenological phases are indicated. B: budburst; F: flowering; BC: bunch closure; V: veraison; H: harvest. Adapted from Pellegrino et al. (2006).

Nitrogen nutrition is also an important issue in vineyards: excessive fertilization might lead to an abundant vegetative development, competing with and then impairing berry maturation (Conradie, 2005). Fertilizers (notably organic ones) are thus barely used or non-existent in some wine growing regions (Celette et al., 2009), which can generate very poor soils (Coll et al., 2011; Salomé et al., 2016). Introducing a service crop in vineyards induces competition with the grapevine for water and nutrients. This competition may be particularly prejudicial for grape yield in non-irrigated vineyards where water resource may be highly limiting. It largely depends on the age of the vines : Ruiz-Colmenero et al. (2011) found that the impact of a competitive species such as *Brachypodium* on grape production was lower for an old rainfed vineyard (more than 40 years) than for two younger rainfed vineyard (4 years), certainly due to a better distribution of the vine root system in soil (deeper for old vineyard) and a greater capacity for water uptake. It also largely depends on the chosen species and their management (Fourie, 2012). Significant soil nitrogen uptake (e.g. up to 40 kg.ha-1 for well-established *Festuca arundinacea Shreb* cover) by the service crops were observed, reducing available N for the grapevine (Celette et al., 2009). The N uptake was low, compared to that observed in other cropping systems as fodder production, but it represented up to 50% of the estimated soil N mineralization. Service crops also compete indirectly for nitrogen by reducing soil nitrogen mineralization as they might change soil temperature slightly, and strongly reduce soil water content (Celette and Gary, 2013). By contrast, Fourie (2012) measured higher inorganic N content under N-fixing service crops compared to bare soil or straw mulch treatment, suggesting that such species selection could reduce competition for nitrogen with grapevines. Other studies have shown the interest of some species entering into summer dormancy to avoid over intensive water competition without destroying them (Volaire and Lelièvre, 2010).

Such competition between the service crop and grapevines is less critical to consider in irrigated and/or fertilized conditions. Nevertheless, even without any irrigation or fertilization, competition may stay moderated by the service crop management (Celette et al., 2009). A non-permanent service crop with barley (*Hordeum vulgare L.*), sown at fall period and buried after grapevine flowering allows for maintenance of higher N content in the soil during the spring period, in comparison with a permanent service crop (*Festuca arundinacea Shreb*). During dry years, non-irrigated grapevines with the non-permanent service crop experienced water stress even comparable to chemically controlled treatment, as service crop growth was also limited by water stress (Celette and Gary, 2013). Finally, the same study suggests that mowing the permanent service crop could moderate or stop its water and N uptake.

3.1.2. Managing a regulation service: the example of biological regulation

Introducing service crops in vineyards may be a direct action lever to increase conservation biological control of pests in agroecosystems. Indeed, this technique may provide flowers or other resources and a better quality habitat for natural enemies. This was examined in vineyards by adding flowering buckwheat (*Fagopyrum esculentum Moench*) and assessing its effect on the parasitism rate of the leafroller (Lepidoptera: Tortricidae) larvae (Berndt et al., 2006). Recently, Irvin et al. (2016) assessed the effect of an irrigated buckwheat service crop on populations of beneficial insects and grape pests in a commercial organic vineyard in southern California. They highlighted that flowering buckwheat was extremely attractive to beneficial insects at the beginning of the trial and also might enhance the abundance of generalist predators. The increase in leafhopper density was attributed to their preference for well-irrigated, vigorously growing vines. In contrast, Berndt et al. (2006) showed that parasitism of leafhoppers was very variable and not always explained by the introduction of buckwheat flowers in the vineyards. These results show that habitat manipulation can enhance parasitism rate but is very tricky to manage to reduce damage done by leafrollers (Berndt et al., 2006). Its effectiveness varies depending on the year or the service crop species. For instance no significant influence was observed for white clover (*Trifolium repens*) and mowed sod (*Dactylis glomerata*).

The movement of natural enemies from floral resources is of particular importance in habitat manipulation research. The distance to which they disperse has consequences for the deployment of floral resources to improve insect natural enemy fitness (Scarratt et al., 2008). Thus, to favour the biological regulation of pests, the landscape scale must also be considered in the design of the agroecosystem (Woltz et al., 2012). To reduce grapevine growth and maintain yield, trade-offs between grape yield and grapevine susceptibility to diseases must be evaluated: Guilpart et al. (2017) showed that water stress at flowering was strongly correlated with both grape yield and susceptibility to diseases (powdery mildew and grey mould), suggesting that service crop management could be a relevant lever to drive soil water status and reach win-win situations.

3.1.3. Managing an environmental service: the example of runoff mitigation

Le Bissonnais and Andrieux (2007) measured runoff water flow and amounts of suspended particles under four soil management strategies: total chemical weeding, spontaneous service crop chemically or mechanically destroyed, and a service crop mixture of 40% *Lolium perenne* and

60% *Festuca rubra*. In such experiments, the service crop mixture had the lowest amount of water runoff, runoff coefficient and soil particle amount lost by runoff, and the highest rainfall threshold for erosion triggering. Novara et al. (2011) also found significant erosion reduction in the presence of service crops, and measured different cumulative soil loss amounts depending on the species. Moreover, the ability of service crops to reduce surface runoff strongly depends on the covering rate (Louw and Bennie, 1991; Novara et al., 2011). Louw and Bennie (1991) measured high runoff when seedlings were too small for a complete soil cover. These experiments highlighted how management levers such as species choice or seedling rate may impact service provision as erosion control.

Service crops are likely to compete with grapevines for water and nutrients, and management strategies should be optimized regarding production objectives. Vinegrowers often decide to cover smaller surfaces to reduce competition with grapevines (e.g. a service crop is maintained only on one inter-row out of two) but such practice also reduces the ability of the service crop to control surface runoff and soil erosion. Ruiz-Colmenero et al. (2011) showed that service crops such as cereals (*Hordeum vulgare* and *Secale cereale* in their experiment) could have a positive impact on runoff and erosion without impairing grape production if cereals were properly managed and mown during the season to mitigate the competition for nutrients. This confirms the results of other experiments in vineyards (Marques et al., 2010) and olive orchards (Gomez et al., 2003).

3.2. Context and phenology dependency of ES provisioning

3.2.1. Soil and climate conditions

The importance of services and disservices caused by the presence of service crops largely depends on soil and climate conditions. Salomé et al. (2016) identified three Mediterranean soil types regarding their carbonate content, stoniness and texture, and analyzed 23 soil quality indicators under various fertilization, weeding and service crop strategies. A temporary service crop significantly changed soil organic carbon and microbial biomass carbon contents compared to a bare soil for only two out of the three soil types. Soil carbonate content was thought to explain such differences, as calcareous soils present more stable soil functioning (buffering of nutrient availability) that may mask the effect of management practices (Salomé et al., 2016). Climate is also a relevant factor impacting ES provisioning and the feasibility of service crop practices. For example, the Mediterranean climate (e.g. South of France) is characterized by mild and rainy winters, drought in summer, and rainfall can be scarce in spring. In such conditions, and when no irrigation is possible, vinegrowers often decide to sow service crops after the grape harvest and to destroy the associated service crop between late winter and grapevine flowering to avoid competition for water. In a Semi-Continental climate (e.g East of France), winter can be harsh, and rainfall are more regularly distributed through the year. Service crops would freeze in winter, and sowing generally occurs in spring or in summer periods as competition for water is less feared. Those differences between climates (rainfall abundance and distribution along the year, extreme temperatures) could have consequences on service crops management (e.g. destruction period, risk of competition with grapevine) and ES provisioning.

3.2.2. Temporality of services

Even if some services can be quite "general" or constant along the year (e.g. SOM improvement), most of ES are time-dependent, and may vary following abiotic (e.g. rainfall occurrence and amount) and biotic (e.g. vine and crop physiology and phenology) conditions. It is essential to take into account the dynamics of ES provision for the management of service crops (Schipanski et al. (2014), Figure 5). Thus, after vine budburst, crop protection requires soil trafficability because of possible rainfall events: on average French vineyards supported 19 pesticide sprays in 2013 (Ambiaud, 2015). After budburst, grapevine growth starts to generate nitrogen absorption (Wermelinger, 1991), and service crop management should be thought to reduce possible competition for soil resources and eventually to promote inorganic nitrogen release to the system (N supply service).

In summer, berry formation and ripening occurs when rainfall events become scarce and temperatures increase. As overly intense water stress can severely impair grape yield, it is important to preserve the water resource in soils (Guilpart et al., 2014). In Mediterranean non-irrigated conditions, mulch formed at budburst after service crop destruction may protect the soil and enhance water availability for grapevines by reducing soil evaporation or increasing rainfall efficiency. Mulch biomass and its persistence at the soil surface depend on management: selection of service crop species, destruction date and machinery (mowing machine, roller-crimper, etc.). The use of perennial species with the trait of summer dormancy may aid maintenance of a mulch without destroying the service crop (Volaire and Lelièvre, 2010).

After the grape harvest, the build-up of N reserves generates another peak of nitrogen absorption (Wermelinger, 1991) and supplying N with service crops may be relevant again. Heavy storm events can be frequent at this period, and erosion risk in sloped vineyards is very high: erosion control will depend on farmers' management strategies

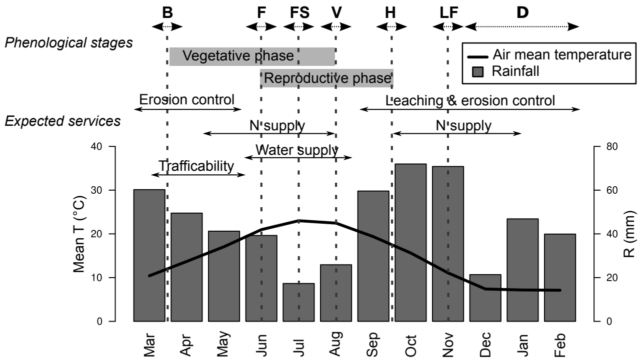

Figure 5: Temporality of expected services in vineyard (Mediterranean region, France). The figure is structured in 3 parts: in the top the grapevine phenolo- gical stages (B: budburst, F: flowering, FS: fruit setting, V: veraison, H: harvest, LF: leaf fall, D: dormancy); in the center the ecosystem services provided by service crops in vineyards according to the period when they are expected; in the lower part Mediterranean climatic data (rainfall and mean temperature) averaged on 2005–2015 period for Roujan station (south of France).

(presence of mulch, sowing date). In winter, rainfall is more frequent and other services such as soil water refilling and N leaching prevention are expected from service crops, and the choice for suitable species could favour this service (e.g. catch crop implantation (Thorup-Kristensen et al., 2003)). This sequence of ES needs is largely dependent on the mean climate and soil conditions as previously mentioned.

The temporality of ES provisioning is important to consider across timescales that are longer than the annual cycle due to the perennial nature of the grapevine. While some services can be realized at a seasonal or yearly scale (e.g. weed control, water infiltration, nitrogen supply. . .), others require a long-term period. For example, organic matter may take several years to increase in soils in the presence of a service crop (Morlat and Jacquet, 2003). The time needed for the biotope to reach a new equilibrium prompts to study the service of biodiversity conservation after several years only.

Short and long term temporal scales have to be considered and not disconnected in order to understand when and how ES emerge over time, and manage the balance between ES properly. Thus, service crops require an adapted management in order to satisfy the farmer's objectives.

3.3. Framework for the management of service crops and ecosystem services

3.3.1. Farmer's objectives and constraints

To determine vinegrower's objectives and constraints, the first step is the identification of the purpose of using service crops, i.e. which ES are targeted. The number of targeted ES determines the level of complexity of the cropping system and its management, and the trade-offs to seek (Rapidel et al., 2015). In agriculture, provisioning services (i.e. food and fiber production) are certainly the first target, as farmer's income directly comes from these ES. However, provisioning service may be associated with other ES such as supporting and regulating services. The farmer's production objective determines most of the subsequent choices concerning the management strategy for the service crops. Then, pedoclimatic conditions (e.g. soil type, soil depth, slope, climate zone) also play a key role in choosing the levers of service crop management that can be activated, pertaining to strategic scale or tactical decisions (Figure 6).

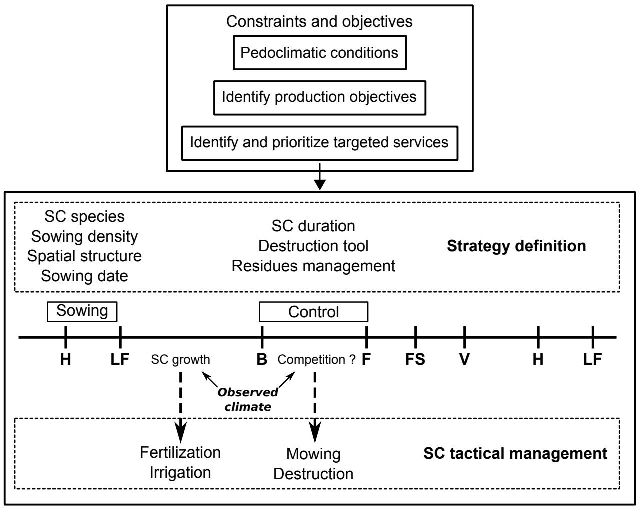

Figure 6: Framework for the choice and management of service crops (SC) in vineyards. Constraints and objectives (part 3.3.1) allow to design the strategy (part 3.3.2), from sowing to service crop control. Depending on observed climate which drives the service crop growth and the risk of competition with grapevine, tactical adjustments (part 3.3.3) can be achieved to provide ecosystem services and satisfy production objectives. H: harvest, LF: leaf fall, B: budburst, F: flowering, FS: fruit setting, V: veraison.

3.3.2. Service crop strategy design

The design of a service crop management strategy in vineyards deals with annual and long-term scales. Associated management levers relate to species choice (sole or mixtures) and installation (sowing date and density), spatial structure in the vineyard, service crop duration and destruction tool (Figure 6 "strategy definition"). The choice of spontaneous or sown cover is also a part of the farmer's strategy (Delabays et al., 2006; Ruiz-Colmenero et al., 2011). Spontaneous vegetation is made up of local weeds that can be controlled and/or destroyed during the

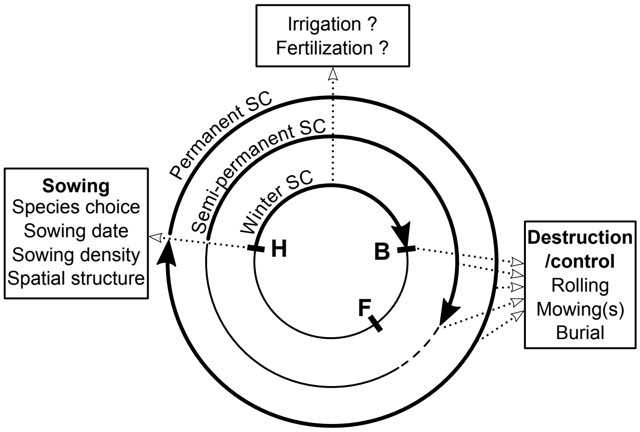

Figure 7: Service crops (SC) management plans in Mediterranean region. H: harvest; B: budburst; F: flowering.

vine cycle. Spontaneous vegetation can be preferred as it embodies a costless intercropping option and may offer interesting trade-offs between ES (Kazakou et al., 2016). However, the production of biomass may be less important than with sown species (Steenwerth et al., 2010). Slow soil coverage or strong competition for water resources are other disadvantages that may be found with spontaneous vegetation (Delabays et al., 2006; Pardini et al., 2002; Ruiz-Colmenero et al., 2011). In the case of sown species, vinegrowers should take into account seed availability and cost, additional workload for seedbed preparation and sowing. However, bred species (e.g. shallow-rooted) could help reducing competition with grapevines (Delabays et al., 2006), and largescale commercial availability allows selecting species and cultivars suited to different environments (Pardini et al., 2002). Moreover, choosing sown species can be interesting to reach one or several specific services, such as long-term SOM improvement with grasses, N-fixation or rapid decomposition for N supply using legumes (Guerra and Steenwerth, 2012).

Sowing density and spatial structure form levers which can be used to reduce competition with grapevines, or to favour biomass production (Santi et al., 2016). Spatial structure refers to service crop location in the field: full surface, only rows or inter-rows, one inter-row out of two or more (Figure 3). Such a choice impacts competition between service crops and grapevines, and thus berry production, particularly in non-irrigated conditions (Ripoche et al., 2011a). Sowing one inter-row out of two might act as partial root-zone drying (PRD) technique, without altering grapevine yield and improving berry quality (Poni et al., 2007; Lopes et al., 2011).

The sowing date is a relevant lever impacting service crop emergence and establishment. In vineyards, studies present little variability, as service crops are generally sown in autumn when soil surface conditions are favourable (Celette et al., 2009, 2008; Novara et al., 2011; Pardini et al., 2002; Ruiz-Colmenero et al., 2011). When targeting nitrate uptake as a service, to avoid leaching, service crops sown in summer are more effective, provided that the weather favours the service crop emergence and establishment (Constantin et al., 2015).

Depending on targeted services, service crop duration, destruction tool and residue management are essential management levers. Service crop duration is linked to the temporal complementarity between grapevines and service crops, and can be adjusted to reach specific services. Figure 7 presents three different temporal management strategies for vineyard associated crops, with an example for the Mediterranean region. Winter service crops refer to service crops destroyed at grapevine budburst, thus only present during grapevine dormancy. In contrast, a permanent service crop is present all through the grapevine cycle. Semi-permanent service crops are destroyed or mown between budburst and harvest depending on climate conditions. Finally, destruction tool and residue management are levers that can produce contrasted ES. Steenwerth et al. (2010) measured soil respiration (primary loss of carbon from ecosystems) under two service crop management practices: mowing and tillage. In the tillage treatment, respiration rates increased up to three times compared to rates measured under mowing. At the same time, burying residues with tillage appears to be more effective for N mineralization (Radicetti et al., 2016). No-till practices are mainly used to produce mulch that may, for example, reduce runoff and erosion (Prosdocimi et al., 2016). As residue fragmentation helps decomposition by microorganisms, using a roller-crimper may produce more persistent mulch. The roller-crimper also decreases production costs as it requires less energy than a running a mower or pulling a plow, and avoids the use of herbicides (Ashford and Reeves, 2003).

3.3.3. Adaptive strategy and tactical management

Tactical levers concern more technical operations at a seasonal time scale. Tactical operations mainly depend on climate and state of the biophysical system during the crop(s) cycle(s) (Figure 6). Field indicators such as predawn leaf water potential or tensiometers can give information about soil and crop water status. For example, grapevine irrigation can facilitate service crop persistence while avoiding over intensive water stress for grapevines (Gaudin and Gary, 2012). Furthermore, the option of irrigating or fertilizing service crops could be considered by vinegrowers (Fourie et al., 2005; Messiga et al., 2016). Fourie et al. (2005) found that oat dry matter production without fertilization represented only 21.6% of oat dry matter produced with fertilization, suggesting that service crop fertilization could be relevant to reach desired biomass before destruction. In another study, organic and industrial wastes were applied together with service crop treatments (Messiga et al., 2016). They showed that coupling service crops and soil amendments (bio-wastes and nutrient-rich industrial by-products) permitted provision of mineral N and available P as classical mineral fertilizers, and improved soil quality (i.e. organic carbon, organic nitrogen, microbial biomass).

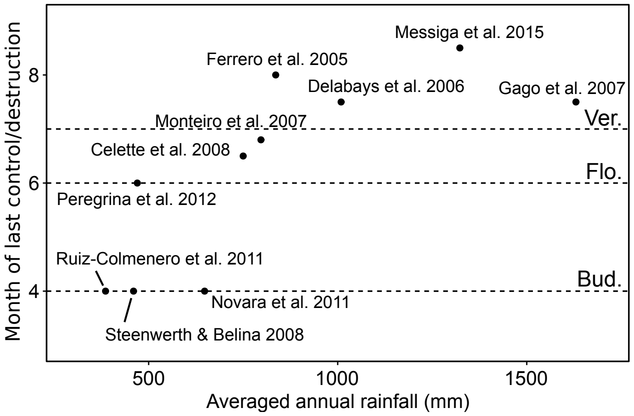

Figure 8: Months of the year (in the Northern hemisphere) corresponding to the last service crop mowing or destruction plotted against averaged annual rainfall given in the 10 cited studies. Bud: budburst; Flo: flowering; Ver: veraison.

The destruction date remains one of the main tactical management levers in vineyards with service crops: in the case of a lack of water early in the season, service crop destruction may stop the transpiration flux and preserve soil water reserves. A short analysis of 10 studies dealing with service crop management issues in a wide range of climates suggests that water availability (represented here as averaged annual rainfall) may be a relevant factor driving service crop destruction or mowing dates in vineyards (Figure 8, see also Guerra and Steenwerth (2012)).

Ensuring durable grape production and runoff mitigation is possible only if adaptive management is applied. Ripoche et al. (2010) carried out simulations of different service crop management options (duration, surface, species) to analyse the balance between yield and runoff mitigation. Results showed that rigid strategies that do not allow for annual adjustments increased the risk of failure. In another study, Ripoche et al. (2011b) simulated flexible strategies, i.e. strategies including management options that are responsive to climate and condition of the biophysical system (Figure 9). This ability to modify management over the years allows combining seasonal and long term management, more closely fitting the idea of "sustainagility" (Jackson et al., 2010). Agricultural operations such as seedbed preparation or destruction of the associated crop were driven by feasibility conditions (e.g. soil moisture in relation with soil tillage, tractor traffic). Simulations showed that flexibility improves sustainability of the vineyard (Figure 9). Then, sowing another service crop in the following year could provide a runoff mitigation service (Ripoche et al., 2011b).

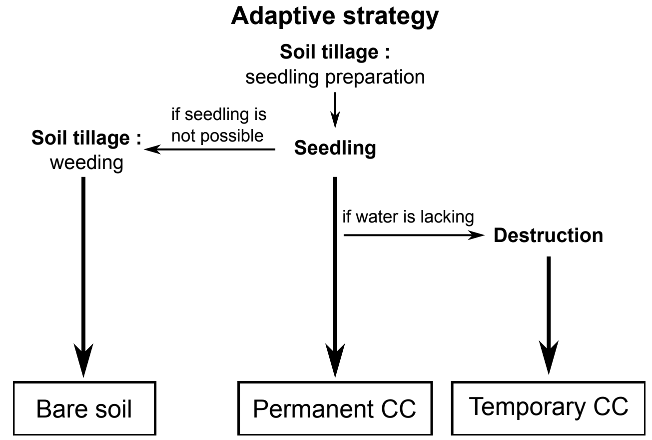

Figure 9: Example of adaptive strategy for inter-cropped vineyards (from Ripoche et al., 2011a,b).

Such flexibility and annual adjustments highlight the need for indicators of system functioning. Soil and water status are essential information allowing farmers to manage water resources, by irrigation or service crop destruction for example. Using tensiometers within the rooting zone at various depths seems to be relevant to easily measure soil water dynamics, and trigger grapevine irrigation when risk of water stress is increasing (Forey et al., 2016). Model-based evaluations of water stress risk are interesting tools that could help monitor irrigation (Gaudin and Gary, 2012). For example, the fraction of transpirable soil water (FTSW) appears to be well correlated to plant water stress (Sinclair and Ludlow, 1986) and models such as WaLIS (Celette et al., 2010), validated in several situations (Delpuech et al., 2010), can be used by professionals to predict water deficit zones at the vineyard scale and to monitor irrigation (Dufourcq et al., 2013). Robust indicators of service crop development are also needed for service crop management. For example, Vrignon-Brenas et al. (2016) used the aboveground biomass of the service crop as an indicator of weed control and N supply. They identified a minimum threshold of about 2 t.ha-1 to provide these ES efficiently. A minimum grass covering rate of 50% was found to be necessary to significantly increase water infiltration rates during rainstorm events (Andrieux, 2007; Wassenaar et al., 2005). Moreover, identifying grapevine stress indicators would be relevant to coordinate vine and service crop management, along with soil resources (Celette and Gary, 2013).

4. CONCLUSION

This paper reviews most of ecosystem services and disservices that can be provided by service crops in vineyards, and proposes a framework for their management. The genericity of most processes may lead to a larger application of the framework, in other cropping systems or with other types of service crops. As an example, we can assume that such a framework could be used for the use of cover crops in arable cropping systems. Nevertheless, the management levers permitted in such cropping systems would be different, as the type and importance of the different expected services. We also underscore the importance of considering long-term objectives in vineyard systems, given that grapevines represent a woody perennial crop. This framework also could be adapted for managing buffer strips and hedgerows, which could be viewed as a service crop within the agricultural landscape. We used the term service crops to highlight the large variety of ES that can be supplied by such crops. Moreover, this term underlines the main objective of growing service crops, which is the provision of services more than marketed products. This might change the management of such service crop in comparison to "cash crops" (e.g. grape, wheat, rice, soybean) which are set to produce marketed products first. Such cash crops are also susceptible to provide ES to the agroecosystem but we distinguished them from services crops as the main expected service from them is the provision of food, fiber or energy that can be sold. We showed that the provision of ES largely depends on farmers' strategies and the tactical operations they set up: service crops need to be managed as does any other crop grown with direct economic purpose. Although not systematically adopted among vinegrowers, the introduction of service crops is developing and could help farmers to overcome the frequent issues that vineyards face (organic matter losses, erosion. . .). As competition with grapevines remains the main reason for service crop rejection, more research is needed to find appropriate species according to the targeted services, and tactical management options to achieve trade-offs between ES without impairing farmers' economic return.

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