Cover crops in viticulture. A systematic review (1):
Implications on soil characteristics and biodiversity in vineyard

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abstract
This work seeks to synthesise the knowledge on the use of cover crops in vineyards in the last 20 years, emphasising on the one hand, soil characteristics such as nutrition, organic carbon, structure or erosion and, on the other hand, environmental factors such as soil and biodiversity in vineyards, and gas emissions.
A systematic review was made using Scopus-index journals for the past 20 years (1999 - 2018). The selection was independently done by two researchers, selecting a total of 272 published papers related to cover crops in the vineyard. Each article was categorised according to its theme and metadata were created, considering all relevant information from an agro-ecological point of view.
The use of cover crops has a positive effect on the vineyard by increasing soil organic carbon (SOC), improving water infiltration and aggregate stability, and reducing erosion and greenhouse gases emission to the atmosphere. Furthermore, there is an increase in biodiversity, both in soil and the vineyard. Finally, cover crops do not constitute as a rule a major competition for nutrients to the vines except for nitrogen when grass covers are used. Contrarily, legume cover crops generally increase N in the soil, although its availability for plants is not immediate.
This review constitutes an objective tool to help growers when considering the use of cover crops in vineyards that, based in a systematic review, provides relevant information depending on the characteristics of the growing condition of the vineyard.

KEYWORDS
nutrition, soil organic carbon (SOC), erosion, water infiltration, aggregate stability, greenhouse gases
INTRODUCTION

The planting schemes commonly used in viticulture, especially trellised systems, leave a large portion of the soil surface uncultivated. The management of this part of the soil has important effects on vegetative growth, yield, plant nutrition and water status, and grape and wine quality, and also on soil characteristics (nutrition, organic carbon, structure or erosion) and environmental factors (soil and vineyard biodiversity, gas emissions).

Although the management of vineyard soils through cover crops shows a growing trend worldwide, even in areas where their use was limited in the past due to lack of rainfall, it is very convenient to set the balance between the pros and cons. This is particularly relevant since there is a great diversity in what can be considered a “cover cropping” in a vineyard. According to their origin, cover crops can be sown or spontaneous. When sown, mixtures of species, but also monocultures, are broadly used, being those in Fabaceae (legume) and Poaceae (grasses) the most widespread ones. Related to this, cover crops can be also classified as annual or permanent, according to the cover crop duration. Variation also occurs with cover crop management, sometimes including harvesting or destruction with tilling or herbicide application. There is also a certain degree of variation in the fraction of the vineyard covered with the crop, which is usually established in the alleys, sometimes covering all the vineyard, and more exceptionally established just under the vines.

Considering all the diversity mentioned above, and taking into account that some additional factors certainly affect their impact in the vineyard, such as variation in climate, soil type, rootstock and irrigation use, it is very relevant to examine in detail the balance between their potential advantages and disadvantages in every situation. Although there are some comprehensive reviews in this issue (Garcia et al., 2018; Steenwerth and Guerra, 2012) that provide interesting compiled information on the effect of cover crops in viticulture, none of them approaches to all the effect of cover crops or, if it does, it is not performed following a systematic process to identify and select research on this topic.

This work aims to compile and analyse, in a systematic way, the information available in recent literature on the effect of cover crops between the rows. Given the extension of the study, this information is presented as two companion papers, this one dealing with the aspects related to soil characteristics and environment-related issues, while a second paper (Abad et al., 2021) analyses the direct impact of cover crops on vineyard performance.

PUBLISHED DATA SOURCING AND SELECTION

Although a standard or consensus definition of a systematic review does not exist (Krnjevic et al., 2019), a systematic review is a review that reports or includes: (1) a research question, (2) sources that were searched, with a reproducible search strategy (naming of databases, naming of search platforms/engines, search date and complete search strategy) (3) inclusion and exclusion criteria, (4) selection (screening) methods.

In our case, we used the Scopus database as the source for extracting publications. The following search query was constructed and applied: TITLE-ABS-KEY (“cover crop” OR “green cover” OR “ground cover” OR “tillage”) AND TITLE-ABS-KEY (“wine” OR “vitis” OR “vineyard” OR “grapevine” OR “grape”), between the years 1999 and 2018. A total number of 584 published papers were obtained (search day: January 20th, 2019).

To these papers, the following exclusion criteria were applied, analysing their titles and abstracts:

- Books, conferences or papers that are not based on a specific experiment.
- Publications about crops different from vines.
- When there is no mention (not even indirect) of cover crops (“nor till”).
- Publications that refer to cover crops only as examples of organically managed vineyards, but not as the main objective of the study.
- Papers presenting results of modelling exercises, without experimental ground-truthing.
- Publications about table grapes.

The selection was independently completed by two people. Those articles excluded by both selectors were directly discarded, but those excluded just by one of the selectors were re-revised. After this process, there were 272 papers remaining.
These articles were categorised according to their theme, and the following metadata were extracted:

- Location
- Vineyard: scion variety and rootstock, planting pattern, age and vine formation
- Experiment duration
- Cover crop characteristics (sown or spontaneous, monoculture or crop mixture, species, cover crop and row management)
- Climate: an illustrative classification was performed; cold (average T below 12 °C), mild (average T between 12 and 15 °C) and warm climate (average T above 15 °C)
- Cultural practices: irrigation (yes/no) and fertilisation (yes/no)
- Soil: texture, organic matter percentage (% OM) and studied horizons

Additionally, all the information regarding the effect cover crops had had on any characteristic relevant from an agro-ecological point of view was extracted and considered for global analysis. In the following sections, the information related to soil characteristics and environmental aspects is presented, whereas a companion compiled and discussed the impact of cover crops on vineyard performance.

**SOIL MinerAAL COMPOSITION**

Grapevine is not very demanding in terms of fertilisation, among other reasons, because the main objective frequently lies in the achievement of high-quality levels more than maximising grape production. However, nitrogen (N) is considered as an important element in grape growing, due to its relevance on vegetative growth and its leaching potential in nitric form in the soil. Other nutrients, such as potassium (K), influence fermenting grape juice. In general, it is perceived that cover crops can compete with vines for soil nutrients (Celette et al., 2009; Steenwerth and Belina, 2008).

### 1. Nitrogen

The impact of cover crops on soil N content is analysed in 14 of the articles selected (Table 1), covering 40 different management strategies. In general terms, the use of legumes as a cover crop provides an increased amount of total N (Ntot = organic + mineral N), as well as of mineral N (Nmin) in the soil due to their role in fixing air nitrogen when legume roots have *Rhizobium* (Peoples et al., 2009). On the contrary, grasses act as major soil N scavengers from the soil, reducing the Ntot content to a greater extent than other families.

**TABLE 1.** Total nitrogen (Ntot) and mineral nitrogen (Nmin) average content of the soil, grouped according to cover crop type/soil management. Prepared from the 14 mentioned articles and Table 2.

| Soil management | Ntot (g/kg) | N data | Nmin (mg/kg) | N data |
|-----------------|------------|--------|--------------|--------|
| Grass           | 0.873      | 4      | 5.475        | 4      |
| Grass + legumes | 1.716      | 7      | -            |        |
| Legumes         | 1.555      | 2      | 17.458       | 5      |
| Spontaneous vegetation | 1.062 | 5 | 7.43 | 1 |
| Tillage control | 1.193      | 4      | 7.515        | 2      |
| Herbicide control | 1.053    | 3      | 1.9          | 1      |
| Herbicide + tillage control | 0.935 | 2 | - | |

As mentioned above, the use of grasses as cover crops leads to decreased N levels in the soil as a general rule, this diminution being, as an average, around 25 % both Ntot and Nmin. This effect was reported in Varga et al. (2012), analysing the role of a spontaneous cover in Hungary, where an impact on vineyard yield was also shown. Commonly used grass cover crops in France (Celette et al., 2009; Gontier et al., 2014), barley cover crops in Turkey (Judit et al., 2011) and La Rioja, Spain (Pérez-Álvarez et al., 2013), and spontaneous or *Festuca arundinacea* cover crops in Italy (Mattii et al., 2005) showed a reduction in soil N content. Occasionally, the observed N reduction could affect grape juice yeast assimilable nitrogen (YAN) (Pérez-Álvarez et al., 2015b).

Accordingly, Rodriguez-Lovelle et al. (2000) identified a soil N reduction with the use of a 2-year *F. arundinacea* cover crop in Montpellier, France, linked to a 30 - 50 % reduction in leaf N content. It was also observed that other factors than N competition could explain the N reduction, such as reduced soil moisture.

Celette et al. (2009) demonstrated that *F. arundinacea* and a 3-year-barley cover crop in Montpellier, France, resulted in an N decrease due to a reduced soil N mineralisation caused by low soil moisture levels. The reduced soil mineralisation was more pronounced in the driest years.
The same authors observed that a *Festuca* cover crop cutting at the beginning of May caused a reduction in the cover crop N uptake. However, an increase in N mineralisation potential was detected with the use of a *F. longifolia* and an 8-year spontaneous cover crop in La Rioja (Peregrina et al., 2010). For their part, Klodd et al. (2016) did not observe N competition in the petiole due to the presence of a grass cover crop in cooler and more humid weather conditions (Virginia, USA). However, a 63 % reduction in the length of absorptive roots at 80 cm depth was shown, as well as a thin hairy-root reduction of 49 % in the first 20 cm of soil. Mycorrhizal colonisation of the grapevines was unaffected (15 - 40 % of the radicular length) by the presence of the cover crop.

Concerning legume-based cover crops, they increased soil N content, this increase being, on average, around 30 % for Ntot and nearly 100 % for Nmin. (Fourie et al., 2007; Messiga et al., 2015; Ovalle et al., 2007; Pérez-Álvarez et al., 2015a; Sulas et al., 2017). However, such N increase sometimes may not modify vine behaviour directly, as observed by Sulas et al. (2017), who estimated that only 10 % of the total 125 kg ha⁻¹ year⁻¹ N fixed by a *Medicago polymorpha* cover was used by the vines, and hypothesised that this limited absorption could be due to a combination of physical, chemical and microbiological processes.

2. Other elements

With respect to phosphorus (P), no significant differences have been generally detected on its availability when comparing the use of cover crops and tillage practices in adult vineyards (Biddocu et al., 2016; DeVetter et al., 2015; Ferreira et al., 2018; Mattii et al., 2005; Pérez-Álvarez et al., 2015a; Ruiz-Colmenero et al., 2011). Grapevine nutritional status remained unaltered concerning P content when cover cropping, according to petiole analysis (Mattii et al., 2005; Pérez-Álvarez et al., 2015a). However, Klodd et al. (2016) observed a reduced P content on cover cropped vines. This reduction could be explained by a redistribution of the vine root system towards deeper less fertile soil layers, due to the competition between cover crop and vine roots.

Regarding soil potassium (K), the general trend observed is that cover crops did not affect content (Fourie et al., 2007; Mattii et al., 2005; Pérez-Álvarez et al., 2015a; Pou et al., 2011).

Vineyard soil mulching, specifically straw mulch, tended to increase P and K content in soil samples (DeVetter et al., 2015). In some cases, supplemental fertiliser applications to ensure cover crop growth could account for the increased soil P and K content (Ovalle et al., 2007). However, cover crops could increase P losses compared to soil tillage, in case of sloppy vineyards when the fertiliser is not covered with the soil (Napoli et al., 2017). On the other hand, P, K and magnesium (Mg) losses in sloped vineyards were 70 - 95 % higher under tillage than in the presence of cover crops, due to sediment transportation by surface runoff of water (Ruiz-Colmenero et al., 2011; Vrsic et al., 2011).

There is much less evidence on the effect of grass cover crops on recently established vineyards, though under some conditions it can promote vine growth at the beginning of the season, probably due to the presence of organic compounds in the cover crop rhizosphere. Nevertheless, at the end of the cycle, the effect becomes negative because of the high degree of competition for nutrients and water (Brunetto et al., 2017).

**SOIL ORGANIC MATTER**

Cover crops increased soil organic carbon (SOC) accumulation in 13 out of the 19 articles selected (see Table 2). The increase observed in SOC was variable, depending on the cover crop type and its presence, both during the season and over the years.

A total of 16 grass cover crops increased SOC by an average of 68.5 % compared to the initial conditions. When legumes were grown as a cover crop, an average increase of 39.2 % was observed (9 cases in total). Finally, the data from 8 spontaneous cover crops, mainly composed of grass species, showed the most favourable results, with a 119.5 % increment in SOC content. In contrast, one of the analysed spontaneous cover crops caused a decline of 0.5 % in the SOC levels (Mattii et al., 2005).

The temporal evolution of SOC in tilled vineyards is quite variable since in the 6 articles found measuring this evolution, in 2 of them it was observed to decrease (Peregrina, 2016; Pou et al., 2011), in another 2 it was not affected (Belmonte et al., 2016; Mattii et al., 2005), while the remaining 2 (García-Díaz et al., 2017; Peregrina et al., 2010) showed an increased SOC content.
As an average, in tilled vineyards, an average increase of 4.05 % per year was observed. Similarly, the evolution of SOC in soils weeded chemically was variable, since in one of the studies it was observed to decrease (Belmonte et al., 2018), whereas, in the other one, it increased (Celette et al., 2009), being the average change of - 0.8 % per year.

The dynamics of SOC increase in cover cropped vineyards are slow, and, for instance, García-Díaz et al. (2016) reported that it took 5 years for the annual incorporation of a Vicia faba cover crop to increase SOC. Pou et al. (2011) observed a decrease in the SOC content with a spontaneous cover crop under deficit irrigation for 3 years in Mallorca, Spain. According to Belmonte et al. (2016), the increase in SOC content is not observed until the third year when a spontaneous grass cover crop was analysed in Italy. In other cases, the use of a Brachypodium distachyon cover crop led to a SOC increase during the first year (Marques et al., 2010), while a rye cover crop did not show the same effect. A higher increase was shown when the cover crop included grasses (Messiga et al., 2015), more than when they were only composed of legume (Table 2).

SOIL STRUCTURE

Altogether with the increase in SOC reported above, soil aggregate stability was also improved by the presence of cover crops when compared to tilled soils (Table 2). Such improvement required a relatively long period to appear. Thus, Belmonte et al. (2016) did not observe changes in aggregate stability until the third year of a spontaneous grass cover crop establishment, whereas Ruiz-Colmenero et al. (2013) detected an increase in SOC and aggregate stability from the second year onwards (30 % increase in aggregate stability compared to tillage). Under some circumstances, a direct interaction between soil microbial population and the development of more stable soil structure has been observed (Virto et al., 2012). Cover crops have also been reported to increase meso- and macro-porosity (Ruiz-Colmenero et al., 2013), or to enhanced pore connectivity and infiltration rates, even if pore size or volume remain unaltered (García-Díaz et al., 2018). Pore connectivity and infiltration rates improved through better aggregate stability, although pore size or volume remained unaltered (García-Díaz et al., 2018).

SOIL EROSION

The use of cover crops is directly associated with a considerable reduction in soil erosion. A number of 12 articles, comprising 29 different soil management practices, were selected for the systematic review (Table 3). As average figures, greater soil losses were detected in herbicide-treated (12 Mg ha⁻¹ year⁻¹) and tilled control plots (11.4 Mg ha⁻¹ year⁻¹). Grass cover crops (1.1 Mg ha⁻¹ year⁻¹), mixtures of grass and legume (2.3 Mg ha⁻¹ year⁻¹), spontaneous cover crops (2.4 Mg ha⁻¹ year⁻¹) and legume cover crops (3.4 Mg ha⁻¹ year⁻¹) were the treatments which showed higher erosion-reducing effects. Erosion rates did not directly match with runoff coefficients, that were higher in tilled control plots (21.8 %) compared to the use of grass cover crops (11.8 %) on average values. These data are biased by the results obtained in Gontier et al. (2014), where both the herbicide-treated control plot and grass cover crop vineyard showed a runoff coefficient of 34 %. Leaving this outlying data aside, the average runoff coefficient for grass cover crops would be 8.2 %, more in line with the observed erosion rates. This coefficient was 1.8 % (one single data) in grass or grass-legume mixtures, and around 8.7 % in case of spontaneous cover crops. There were no available data for legume cover crops.

Most of the studies evaluating the impact of cover cropping in erosion were performed in Mediterranean climate conditions (Table 3), where strong storms occur more frequently in the summer, showing that cover crops can play an important role on soil protection during this season (Bagagiolo et al., 2018; Biddoccu et al., 2015; Vrsic et al., 2011). Nevertheless, attention should also be paid to erosion events occurring in autumn and winter. For instance, a study performed in Portugal, in an area where 1200 mm of annual rainfall concentrates in winter, showed the highest losses to occur at this time of year (Ferreira et al., 2018). Similarly, in Sicily (Italy), Novara et al. (2013) observed that the autumn-winter rains resulted in greater runoff and the most severe erosion of the year; and also in Carpeneto, Italy, maximum runoff occurred in winter months, while most rainfall takes place in autumn (Biddoccu et al., 2016). Factors that could explain this behaviour were the reduced cover crop density when the vegetative growth stops and the increased soil compaction due to the employed mechanical tillage practices.
### TABLE 2. Initial and final soil organic carbon (SOC), final nitrogen (N) content in the soil and aggregate stability from analysed publications.

| N | Location                  | Duration | Soil management | Cover type | Initial SOC (g/kg) | Final SOC (g/kg) | ΔSOC (%) | Final soil N Ntot (g/kg) | Final soil N Nmin (mg/kg) | Depth (cm) | Aggregate stability |
|---|---------------------------|----------|-----------------|------------|-------------------|-----------------|----------|--------------------------|----------------------------|------------|---------------------|
| 1 | Kreinbacher, Turkey       | 3        | Tillage         | CT         | 9.28              | 8.72            | 6.2      | 0.60 Ntot                | 0.71 Ntot                   | 0 - 30     |                     |
|   |                           |          | Spontaneous vegetation | SV         |                   |                 |          |                          |                            |            |                     |
| 2 | La Caple, France          | 4        | Herbicide + tillage | CTH        | 6.2               | 6.03            | -2.74    | 0.82 Ntot                | 0.60 Ntot                   | 0 - 15     |                     |
|   |                           |          | Permanent cover Festuca rubra, Lolium perenne | G          | 8.55               | 37.9            |          |                          |                            |            |                     |
| 3 | Agugliano, Italy          | 7        | Tillage (depth 5 - 8 cm) | CT         | 7.52               | 1.64            | 80.64    | 0.93 Ntot                |                            | 0 - 50     |                     |
|   |                           |          | Spontaneous vegetation | SV         | 8.32               |                 |          |                          |                            |            |                     |
| 4 | Tokaj, Hungary            | 3        | Herbicide       | CH         | 8.58              | 5.93            | 0.78     | 0.76 Ntot                |                            | 0 - 30     |                     |
|   |                           |          | Permanent cover Festuca arundinacea | G          | 8.41               | 3.83            | 0.82     | 0.76 Ntot                |                            | 0 - 30     |                     |
| 5 | Montpellier, France       | 5        | Herbicide       | CH         | 10.7              | 0.50            |          |                          |                            | 0 - 10     |                     |
|   |                           |          | Spontaneous vegetation Paspalum notatum, L. multiflorum, Bromus auleticus, Desmodium spp., Vicia sativa | SV         |                   |                 |          |                          |                            |            |                     |
| 6 | Santana do Livramento, Brazil | 2     | Herbicide       | CH         | 1.28              | -1.54           | 0.88     | 0.67 Ntot                |                            | 0 - 10     |                     |
|   |                           |          | Annual cover Secale cereale | G          | 2.5               | 92.31           | 0.78     | 0.76 Ntot                |                            | 0 - 10     |                     |
|   |                           |          | Annual cover Avena sativa | G          | 1.69               | 30.0            | 0.78     | 0.76 Ntot                |                            | 0 - 10     |                     |
|   |                           |          | Annual cover A. strigosa | G          | 1.3               | 19.69           | 0.82     | 0.76 Ntot                |                            | 0 - 10     |                     |
| 7 | Western Cape, South Africa| 10       | Herbicide       | CH         | 13.3              | 11.0            | 0.88     | 0.76 Ntot                |                            | 0 - 10     |                     |
|   |                           |          | Permanent cover Medicago sp., A. sterilis, Lotus ornithopodioides, Trifolium scabrum, Chrysanthemum coronarium | GL         | 11.0              | -17.29          | 0.78     | 0.76 Ntot                |                            | 0 - 10     |                     |
|   |                           |          | Annual cover T. resupinatum, M. truncatula, T. subterraneum, Dactylis glomerata | GL         | 13.3              | 0                | 0.78     | 0.76 Ntot                |                            | 0 - 10     |                     |
| 8 | Mallorca, Spain           | 3        | Herbicide       | CH         | 26.64             | 22.76           | 0.83     | 0.67 Ntot                |                            | 0 - 15     |                     |
|   |                           |          | T. pratenses, Triticum aestivum or S. cereale | GL         | 17.75             | -18.2           | 0.78     | 0.76 Ntot                |                            | 0 - 15     |                     |
| 9 | California, U.S.A.        | 5        | Tillage         | CT         | 12.8              | 3.76            | 0.83     | 0.67 Ntot                |                            | 0 - 15     |                     |
|   |                           |          | Annual cover Triticale x Triosecale | G          | 10.8               | 21.9            | 0.83     | 0.67 Ntot                |                            | 0 - 15     |                     |
| 10| Región Maule, Chile       | 2        | Herbicide       | CH         | 5.0               | 0.01            |          |                          |                            | 0 - 15     |                     |
|   |                           |          | Permanent cover T. subterraneum, M. polymorpha | L          | 10.8               | 21.9            | 0.83     | 0.67 Ntot                |                            | 0 - 15     |                     |
|   |                           |          | Permanent cover T. subterraneum, T. michelianum | L          | 9.92               | 14.1            | 0.83     | 0.67 Ntot                |                            | 0 - 15     |                     |
| 11| California, U.S.A.        | 3        | Herbicide       | CH         | 19.28             | -11.15          | 0.86     | 0.67 Ntot                |                            | 0 - 5      | +                   |
|   |                           |          | Permanent cover Valpia myuros, B. hordeaceus, T. hirtum, T. pratenses | GL         | 26.64             | 22.76           | 2.45     | 0.67 Ntot                |                            | 0 - 5      | +                   |
|   |                           |          | Annual cover Vicia faba, Pisum sativum, Triticum aestivum or S. cereale | GL         | 17.75             | -18.2           | 1.70     | 0.67 Ntot                |                            | 0 - 5      | +                   |
| 12| Ligurian Apennines, Italy | 3        | Tillage         | CT         | 5.0               | 0.01            |          |                          |                            | 0 - 5      | +                   |
|   |                           |          | Spontaneous vegetation | SV         | 11.8              | 136.0           | 0.01     | 0.67 Ntot                |                            | 0 - 5      | +                   |
| 13| Brunello di Montalcino, Italy | 5     | Herbicide       | CH         | 9.45              | 0.01            |          |                          |                            | 0 - 15     |                     |
|   |                           |          | Permanent cover F. arundinacea | G          | 12.76             | 35.03           | 1.2      | 0.67 Ntot                |                            | 0 - 15     |                     |
| 14 | Burgundy, France | 10 | Herbicide | CH | 13.9 |
|----|-----------------|----|-----------|----|------|
|     |                  |    | Permanent cover clover | L  | 25.6 | 0 - 5 + |
|     |                  |    | Permanent cover Festuca sp. | G | 32.4 |
| 15 | Badajoz, Spain  | 1  | Tillage (3/ season, depth 10 - 15 cm) | CT | 1.68 | 0.23 Ntot |
|     |                  |    | Spontaneous vegetation | Elytricha repens, F. arundinacea, Portulaca oleracea | SV | 13.70 | 0.64 Ntot |
|     |                  |    |                                 |     |      |
| 16 | Madrid, Spain   | 4  | Tillage (2 - 3/ season, depth 15 cm) | CT | ≈ 11.0 | ≈ 65.4 |
|     |                  |    | Permanent cover Brachypodium distachyon | G | 5.20 - 8.10 | ≈ 95.5 |
|     |                  |    | Spontaneous vegetation | SV | ≈ 14.5 | ≈ 118.0 |
| 17 | La Rioja, Spain | 4  | Tillage (3 - 4/ season, depth 15 cm) | CT | ≈ 6.5 | ≈ 20.6 |
|     |                  |    | Spontaneous vegetation B. mollis, H. marinum, Diplotaxis erucoides, Sonchus asper, Sonchus oleraceus, Veronica latifolia, Comiza canadensis, Papaver hibrimum | SV | 5.39 | ≈ 224.7 |
|     |                  |    | Permanent cover Festuca glauca | G | ≈ 20.0 | ≈ 271.1 |
| 18 | Madrid, Spain   | 2  | Tillage | CT | 9.8 |
|     |                  |    | Annual cover S. cereale | G | 10.4 | 0 - 10 |
|     |                  |    | Permanent cover Brachypodium distachyon | G | 10.5 |
| 19 | Taisen Valley, Austria | 10 | Annual legumes cover with tillage (5/season, depth 5 - 10 cm) | L | 27.3 | 1.61 Ntot |
|     |                  |    | Spontaneous vegetation | SV | 35.2 | 2.14 Ntot |
| 20 | Nueva Escocia, Canada | 2 | Tillage + herbicide (depth 10 cm) | CTH | 15.57 | 1.27 Ntot |
|     |                  |    | Annual cover A. sativa, P. sativum, V. villosa | GL | 15.57 | 1.42 Ntot |
|     |                  |    | Annual cover A. sativa, T. pratense | GL | 17.21 | 1.42 Ntot |
|     |                  |    | Permanent cover Pneum pratense (70 %), T. hibridum (15 %), T. pratense (15 %) | GL | 17.21 | 1.42 Ntot |
| 21 | La Rioja, Spain | 10 | Tillage (3 - 4/ season, depth 15 cm) | CT | ≈ 6.0 |
|     |                  |    | Spontaneous cover | SV | < 11.6 | ≈ 22.0 |
|     |                  |    | Permanent cover F. longiflora - 4 years, B. cartharticus - 6 years | G | ≈ 15.0 |
| 22 | Navarra, Spain  | 1 - 5 | Permanent cover F. arundinacea, L. multiflorum - 1 year | G | 15.7 | 0 - 5 + |
|     |                  |    | Permanent cover F. arundinacea, L. multiflorum - 5 years | G | 12.5 |
| 23 | Iowa, U.S.A.    | 7  | Tillage | CT | 9.15 |
|     |                  |    | Herbicide | CH | 0 - 7.6 + |
|     |                  |    | Straw mulch | M |
|     |                  |    | Cover Festuca rubra | G |
| 24 | Madrid, Spain   | 3  | Annual cover S. cereale | G | 0 - 5 + |
|     |                  |    | Permanent cover Brachypodium distachyon | G | 0 - 5 + |

1: Varga et al. (2012); 2: Gontier et al. (2014); 3: Agnelli et al. (2014); 4: Judit et al. (2011); 5: Celette et al. (2009); 6: Brunetto et al. (2017); 7: Fourie et al. (2007); 8: Pou et al. (2011); 9: Steenwerth and Belina (2008); 10: Ovalle et al. (2007); 11: Belmonte et al. (2018); 12: Belmonte et al. (2016); 13: Mattii et al. (2005); 14: Bartoli and Dousset (2011); 15: López-Piñeiro et al. (2013); 16: García-Díaz et al. (2018); 17: Peregrina et al. (2010); 18: Marques et al. (2010); 19: Zehetner et al. (2015); 20: Messiga et al. (2015); 21: Peregrina (2016); 22: Virto et al. (2012); 23: DeVetter et al. (2015); 24: Ruiz-Colmenero et al. (2013).

N: number-author reference; Duration: years since cover crop establishment; Initial SOC: soil organic carbon at the beginning of the experiment; ∆SOC: variation between final SOC and initial SOC; Depth: sampling depth; Cover type: CT, tillage control; CH: herbicide control; CTH: tillage + herbicide control; G: grass; GL: grass + legume; L: legume; SV: spontaneous vegetation; M: mulch; Ntot: total N (organic N + mineral Nitrogen).
TABLE 3. Summary of runoff coefficients, soil erosion losses and vineyard description from analysed articles.

| N  | Location       | AP(mm) | Slope (%) | Duration | Soil management                          | Cover type | C (%) | Annual erosion (Mg/ha-year) |
|----|----------------|--------|-----------|----------|-----------------------------------------|------------|-------|----------------------------|
| 1  | Toscana, Italy | 695    | 4 - 30    | 8        | Tillage (1/ season)                      | CT         | 9.4   | 8.59                       |
|    |                |        |           |          | Spontaneous vegetation                   | SV         | 8.3   | 7.78                       |
| 2  | La Caple, France | 583   | 10        | 4        | Herbicide                                | CH         | 34.0  | ≈ 12.0                    |
|    |                |        |           |          | Permanent cover *Festuca rubra*, *Lolium perenne* | G          | 34.0  | ≈ 0.7                      |
| 3  | Champagne, France | 757   | 5 - 7     | 7        | Tillage                                  | CT         | 80.0  |                           |
|    |                |        |           |          |                                        |            |       |                           |
| 4  | Maribor, Slovenia | 1045 | 34        | 5        | Tillage alternately                      | CT         |       | 1.89                       |
|    |                |        |           |          | Spontaneous vegetation                   | SV         | 0.09  |                           |
| 5  | Piemont, Italy | 905    | 15        | 14       | Tillage (Depth 25 cm)                    | CT         | 27.1  | 12.3                       |
|    |                |        |           |          | Permanent cover grass                    | G          | 9.6   | 2.2                        |
| 6  | Piemont, Italy | 965    | 15        | 12       | Tillage (Depth 25 cm)                    | CT         | 17.4  | 10.4                       |
|    |                |        |           |          | Tillage (Depth 15 cm)                    | CT         | 15.3  | 24.8                       |
|    |                |        |           |          | Spontaneous vegetation                   | SV         | 10.3  | 2.3                        |
| 7  | Abruzzo, Italy | 21     | 3         | 3        | Tillage (2 - 3/ season)                  | CT         | 5.6   |                           |
|    |                |        |           |          | Annual cover *Hordeum vulgare* (60 %), *Vicia faba* (40 %) | GL        | 1.8   |                           |
| 8  | Piemont, Italy | 849    | 15        | 14       | Tillage (Depth 25 cm)                    | CT         | 18.0  | 7                          |
|    |                |        |           |          | Tillage (Depth 15 cm)                    | CT         | 16.0  | 20.7                       |
|    |                |        |           |          | Spontaneous vegetation                   | SV         | 10.0  | 1.8                        |
| 9  | Sicilia, Italy | 589 ± 175 | 15.9     | 10       | Tillage (3 - 4/season, depth 15 cm)      | CT         | 8     |                           |
|    |                |        |           |          | Annual cover *V. faba*                   | L          | 4.8   |                           |
|    |                |        |           |          | Annual cover *V. faba*, *V. sativa*      | L          | 2     |                           |
| 10 | Madrid, Spain | 400    | 7 - 13.5  | 2        | Permanent cover *Brachypodium distachyon* | G          | 15.8  |                           |
|    |                |        |           |          | Spontaneous vegetation                   | SV         | 9.2   |                           |
| 11 | Piemont, Italy | 850    | 15        | 10       | Tillage (Depth 25 cm)                    | CT         | 21.0  | 11.15                      |
|    |                |        |           |          | Tillage (Depth 15 cm)                    | CT         | 19.0  | 20.7                       |
|    |                |        |           |          | Spontaneous vegetation                   | SV         | 14.0  | 2.60                       |
| 12 | Madrid, Spain | 386    | 8 - 14    | 2        | Tillage (3 - 4/ season)                  | CT         | 4.6   | 0.008                      |
|    |                |        |           |          | Permanent cover *Brachypodium distachyon* | G          | 0.9   | 0.001                      |
|    |                |        |           |          | Annual cover *Secale cereale*            | G          | 1.1   | 0.002                      |
|    |                |        |           |          | Annual cover *H. vulgare*                | G          | 2.7   | 0.003                      |
|    |                |        |           |          | Spontaneous vegetation                   | SV         | 0.3   | 0.002                      |

1: Napoli et al. (2017); 2: Gontier et al. (2014); 3: Morvan et al. (2014); 4: Vrsic et al. (2011); 5: Bagaglio et al. (2018); 6: Biddoccu et al. (2015); 7: Ramazzotti et al. (2008); 8: Biddoccu et al. (2016); 9: Novara et al. (2011); 10: Garcia-Díaz et al. (2017); 11: Biddoccu et al. (2014); 12: Ruiz-Colmenero et al. (2011);
N: number-author reference; AP: average annual precipitation; Duration: in years since the beginning of the experiment; C: runoff coefficient.
Rainfall erosivity was also related to the topography of the vineyard. In Italy, Bagagiolo et al. (2018) observed that high-intensity rains (> 16 mm hour -1) in 15 to 35 % sloped vineyards resulted in higher soil losses when vines were planted along contour lines. On the contrary, in vineyards disposed following the maximum slope line, long-duration rainfall events (> 50 hours) caused the highest soil loss.

The effectiveness of cover crops in the control of soil losses also depends on plant cover duration. The continuous presence of perennial cover crops showed reduced erosion rates compared to temporal plant covers that are mowed in spring (Ruiz-Colmenero et al., 2011; Usón et al., 1998).

Legume-based cover crops showed different effectiveness in controlling soil erodibility. A smaller erosion-reducing effect was associated with a Vicia faba annual cover crop in Sicily compared to a mixture of legume species or grass-legume mixtures, probably due to its lower biomass production (Novara et al., 2011). Soil aggregate stability was found to be an important parameter affecting soil erosion (Ruiz-Colmenero et al., 2013), but soil type could also account for reduced soil losses. In this sense, García-Díaz et al., (2016) observed that silty soils were more prone to erosion.

The effect erosion had on soil loss was accompanied by carbon and nutrient losses, dragged through soil particles. This fact was reported for K, P and N (both as ammonium and nitrates) in Biddocu et al. (2016) and Ferreira et al. (2018), whereas García-Díaz et al. (2017) observed N losses occurring as nitrates while ammonium remained unaltered.

**SOIL BIODIVERSITY**

The use of cover crops results as a general rule in a remarkable increase in soil microbial diversity (Table 4). The enhanced soil microbial biomass and activity associated to cover crops is majorly concentrated in soil top layers (0 - 5 cm), mainly as a consequence of the increase in SOC content mentioned above. In particular, it is the particulate organic matter C which most relevantly increases nutrient availability to microorganisms (Agnelli et al., 2014; Belmonte et al., 2018; García-Díaz et al., 2018; Peregrina et al., 2010; Peregrina et al., 2014).

In this regard, López-Piñeiro et al. (2013) observed an improvement in soil microbial amount and biodiversity after a 6-year natural vegetation management regime in Spain. Soil microbial activity, measured separately for different groups of yeasts and bacteria, was positively affected by the presence of a spontaneous cover crop during 5 years (Peregrina et al., 2014). Zehetner et al. (2015) observed an increased SOC content with a dense grass cover compared to tillage which showed a positive influence on soil microorganisms.

The response of fungi and bacteria to the changes in soil management strategies is not the same, Likar et al. (2017) observing that bacteria were more sensitive to them. In a long term experiment (22 seasons), where the incorporation of the cover crop into the soil was done either every year or just mown, microbial activity was observed to be favoured by mowing (Belmonte et al., 2018). Even distance between rows seemed to influence soil microorganisms. A distance of 70 cm of the grapevine row showed higher microbial activity than a 120 cm distance, regardless of the cover crop species (grasses, legumes or brassicas) (Mackie et al., 2014).

Regarding earthworm populations, a three-fold increase in the number of individuals has been associated to cover crop inclusion in the management system and, conversely, a decrease is observed linked to herbicide applications (Vrsic et al., 2011). Last, in a study comparing the influence of soil management on springtail species, tillage was observed not to affect their diversity, although there was a relevant decrease in the densities of the biggest species (Buchholz et al., 2017).

**BIODIVERSITY IN VINEYARD**

The implication of cover crops on arthropods, small mammals and bird populations were analysed in 24 of the articles selected. In 72 % of the cases considered, cover crops increased the presence of species acting as natural enemies for vineyard pests. In particular, the Hymenoptera population increased in 86 % of cases, minute pirate bugs (Anthocoridae) in 80 %, spiders in 40 % and mites, as well as thrips (Aeolothripidae), in 100 % of cases. The diversity and density of pollinator insects, birds and small mammals also increased in all cases (Table 4).

Increasing plant biodiversity through cover crops was observed to cause a positive effect on the bee population. A study performed in California evaluated bee response to the use of different summer flowering cover crops
TABLE 4. Collection of data from articles that study the influence of cover crops in vineyards on arthropods and vertebrates. *Control treatment.

| N   | Location                  | Soil management       | Cover type | Climate | Irrigation | Duration | Arthropods |
|-----|---------------------------|-----------------------|------------|---------|------------|----------|------------|
| 1   | Douro Region, Portugal    | Spontaneous vegetation| SV         | M       | 1          |          |            |
| 2   | Córdoba, Spain            | Avena sativa (70 %),  | GL         | W       | 1          |          |            |
| 3   | France                    | Bared soil*/ Spontaneous vegetation | C/SV     | M       | 2          |          |            |
| 4   | Douro Region, Portugal    | Spontaneous vegetation| SV         | M       | 1          |          |            |
| 5   | Barrosa, Australia        | A. sativa*/ Austrodanthonia richardsonii/ Chloris truncata/ Atriplex sp. | CG/G/O   | M       | Y 2        | +        |            |
| 6   | Zadar, Croatia            | Tillage*/ Spontaneous vegetation | CT/SV    | M       | 1          | +        |            |
| 7   | Modena, Italy             | Grass*/ Lobularia maritima/ Phacelia tanacetifolia/ Fagopyrum esculentum/ V. faba/ A. sativa | CG/O/O/L/G | M     | 3          | +        |            |
| 8   | Geneva Canto, Switzerland | Herbicide*/ Spontaneous vegetation/ Festuca rubra, Trifolium repens/ T. repens, Lotus corniculatus | CH/SV/GL/GL | C     | 1          |          |            |
| 9   | New York County, U.S.A.   | Dactylis glomerata*/ F. esculentum/ T. repens | CG/O/L | C       | 2          |          |            |
| 10  | Nimes, France             | Tillage*/ Herbicide*/ Spontaneous vegetation | CT/CH/CV | M       | 2          |          |            |
| 11  | Zagreb, Croatia           | Agrostis alba, D. glomerata, F. rubra, Poa pratensis, L. corniculatus, T. repens | GL      | C       | 2          | +        |            |
| 12  | California, U.S.A.        | Tillage*/ F. esculentum | CT/O      | W       | Y 1        |          |            |
| 13  | Valais, Switzerland       |                        | C         |          | 4          |          |            |
| 14  | California, U.S.A.        | Helianthus annuus, F. esculentum | O      |          | W 2        |          |            |
| 15  | Marche, Italy             | Tillage*/ Tillage, herbicide*/ Spontaneous vegetation | CT/CTH/SV | M       | 2          |          |            |
| 16  | Malaga, Spain             | Tillage*/ Spontaneous vegetation | CT/SV    | W       | Y 1        |          |            |
| 17  | California, U.S.A.        | Tillage*/ P. tanacetifolia, Ammi majus, Daucus carota/ Spontaneous vegetation | CT/O/SV  | W       | Y 1        |          |            |
| 18  | California, U.S.A.        | Tillage*/ F. esculentum | CT/O      | W       | Y 1        | +        |            |
| 19  | New South Wales, Australia| Tillage*/ Spontaneous vegetation/ Brassica juncea, Borago officinalis, Coriandrum sativum, F. esculentum, L. maritima | CT/SV/O  | W       | 1          |          |            |
| 20  | California, U.S.A.        | Untreated*/ Tillage/ Herbicide/ Bromus carinatus | CU/T/H/G | W       | Y 2        | +        |            |
| 21  | California, U.S.A.        | Tillage, spontaneous vegetation alternately*/ P. tanacetifolia, A. majus, D. carota | T, SV/O  | W       | Y 2        | +        |            |
| 22  | California, U.S.A.        | Tillage*/ H. annuus, F. esculentum | T/O      | W       | 2          |          |            |
| 23  | Melbourne, Australia      | Adjacent vegetation    | O         | M       | 1          |          |            |
| 24  | Auckland, New Zealand     | T. subterraneum/ T. repens/ T. incarnatum/ T. fragiferum | L      | GH      |            |          |            |

1: Gonçalves et al. (2017); 2: Barrio et al. (2012); 3: Vogelweith and Thiéry (2017); 4: Gonçalves et al. (2018); 5: Danne et al. (2010); 6: Franin et al. (2016); 7: Burgio et al. (2016); 8: Pêtremand et al. (2017); 9: English-Loeb et al. (2003); 10: Renaud et al. (2004); 11: Baric et al. (2008); 12: Irvin et al. (2018); 13: Buehler et al. (2017); 14: Nicholls et al. (2000); 15: Minuz et al. (2013); 16: Duarte et al. (2014); 17: Wilson et al. (2018); 18: Irvin et al. (2016); 19: Begum et al. (2006); 20: Sanguankeo and León (2011); 21: Wilson et al. (2017); 22: Nicholls et al. (2008); 23: Smith et al. (2015); 24: Sandanayaka et al. (2018);
| N | Hymenoptera | Anthocorini | Cicadellidae | Spiders | Mites | Thrips | Others |
|---|-------------|-------------|-------------|---------|-------|--------|--------|
| 1 | = NE(D)     | + / =       |             |         |       |        | Ants   |
| 2 | + P         |             |             |         |       |        | Rabbits|
| 3 | - P         | + / + PL, NE(D) | = NE     | Phalangium opilio |
| 4 |             | +           |             |         |       |        | Predators|
| 5 | + NE (D)    | + NE    |             | Dermatoptera, tephridae |
| 6 | +           | =         |             | Coleoptera |
| 7 | + NE (PP)   | + NE(D)   |             |          |
| 8 |             | +         |             | Syrphidae |
| 9 | + NE (PP)   |          |             |          |
| 10|             | +         |             | Collembola|
| 11|             |           |             |          |
| 12| + NE        | + NE      | + NE (D)    | Woodlark |
| 13|             | +         |             |          |
| 14| + NE (PP)   | + NE (D)  | - P         | Coccinellidae, Chrysoperla |
| 15|             | +         |             | Disease vectors |
| 16|             | +         |             | Passerine birds |
| 17|             | +         |             | Bees |
| 18|             | + NE (D)  |             |          |
| 19| + NE (PP)   | + / =     | P           | Epiphyas postvittana |
| 20|             |           |             |          |
| 21| =           | + NE      = P + NE |
| 22| + NE (PP)   | = NE      - P   = NE Coccinellidae, syrphidae |
| 23| + NE (PP)   |           |             |          |
| 24|             | NE        |             | Pseudococcus calceolariae, P. longispinus |

N: number-author reference; Duration: in years since the beginning of the experiment; C: cold climate (average T > 12 °C); M: mild climate (average 12 - 15 °C); W: warm climate (average T < 15 °C); *: Control management; GH: green house; Cover type: CT, tillage control; CH: herbicide control; CTH: tillage + herbicide control; CU: Untreated control; T: Tillage; G: grass; GL, grass + legume; L: legume; SV: spontaneous vegetation; O: other cover crop group; PE: pest; NE: pest natural enemy; (D): predatory of pests; (PP): parasitic of pests.
(Phacelia tanacetifolia, Ammi majus, Daucus carota) compared to tilled soils and natural vegetation (Wilson et al., 2018). The study revealed that diversity and abundance of wild bees were increased with the cover crops composed of flowering species.

The presence of cover crops favoured vertebrate abundance in comparison with that in bare soils. Buehler et al. (2017) observed that woodlarks prefer nesting in cover cropped plots, particularly in fields with taller and denser ground covers. Besides, nest predation risk was lower in the presence of cover crops. The abundance and diversity of passerine birds were higher in vineyards with herbaceous cover crops than in those under conventional management (bare soil and soil tillage) (Duarte et al., 2014). An increase in the rabbit population in vineyards due to the presence of cover crops has also been reported (Barrio et al., 2012).

In general, the number of natural enemies increased with the introduction of cover crops, though this variation in the natural enemies did not have a direct effect on pests in all studies (Danne et al., 2010; Irvin et al., 2016). One of the best studies of natural enemy groups is Hymenoptera, for which there are different examples of parasitoids which increase when cover crops are used. The presence of Anagrus, egg parasitoids of Cicadellidae, increased with cover cropping (Begum et al., 2006; Centinari et al., 2016; English-Loeb et al., 2003; Nicholls et al., 2008, 2000; Smith et al., 2015) and Erythronoeura (Cicadellidae) population, in turn, decreased. The only exception found to this behaviour is an experiment performed in California, where the presence of cover crops did not affect Anagrus (Wilson et al., 2017). The parasitism rate of Epiphas postvittana (pest) and Trichogramma carverae (parasite) was also increased. In this study, the presence of a sown cover crop had the strongest effect on parasitism rate, in comparison to a spontaneous cover crop or tilled soils. However, some sown cover crops, such as Lobularia maritima, provided higher longevity for the pest than spontaneous cover crops or tillage, and there were no differences in Borago officinalis and Fagopyrum esculentum covers compared to control plots (Begum et al., 2006).

The difference between sown cover crops and spontaneous vegetation was the presence of flowers. Some authors pointed to a link between parasitism rate increase and higher availability of floral nectar as a source of nutrition. English-Loeb et al. (2003) compared Anagrus longevity and parasitism rate of Erythroneura spp. in a laboratory study. Both parameters were greater when adults had access to flowering Fagopyrum esculentum rather than plants without flowers. Moreover, the longevity of Anagrus was increased when provided with honey or sugar water compared to water only. In field experiments, it was also observed that the rate of parasitism increased (Daane et al., 2018; Nicholls et al., 2008) or remained unaltered (Nicholls et al., 2000) when cover crops were established.

Regarding arachnid populations, the effect of cover crops was highly variable. In some cases, the presence of cover crops led to a decrease in spider populations (Daane et al., 2018), maintained them unaltered (Fratin et al., 2016; Gonçalves et al., 2017), or caused an increase (Irvin et al., 2018; Wilson et al., 2017) in spiders known to be predators of pest insects. Cover crop management enhanced predatory mite densities (Burgio et al., 2016). In France, an increase in the number of individuals of the predatory mite Typlodromus pyri was observed, while the number of the mycophagus mite Orthotydeus lambi and the pest mite Panonychus ulmi decreased in cover cropped vineyards (Vogelweith and Thiéry, 2017).

A positive response of predatory thrips (spiders, Nabis sp., Orius sp., Geocoris sp., Coccinellidae and Chrysperla sp.) to cover cropping has also been observed, while reduced densities of western flower thrips pest (Frankliniella occidentalis) have been reported in cover-cropped plots (Nicholls et al., 2000).

The presence of natural enemies in the cover crop does not mean that they will be present in the vines themselves. Gonçalves et al. (2018) showed that, although predators could colonise the vineyard, it is more probable that they feed primarily on vineyard pests that spend part of their life cycle on the ground or use plants from ground cover as alternative hosts. With this regard, the abundance of grape pests has been reported to be higher on grape leaves compared to their presence on the cover crop itself, while the presence of beneficial insects was higher on cover crop (Irvin et al., 2016). Concerning the impact of the presence of cover crops, it has been observed that the increase in the populations of natural enemies of a cover cropped with respect to a tilled one is greater on the ground than on the grapevine canopy (Wilson et al., 2017).
Cover crop mowing could be an effective tool to increase the abundance of natural enemies on vine canopy. In California, Nicholls et al. (2008) showed that numbers of leafhoppers declined in vines when the cover crop was mown, while the cutting of the cover crop vegetation increased Anagrus densities on the vines, especially one week after mowing.

The presence of natural enemies is also influenced by cover crop types. When three native cover crops were compared to a sown Avena sativa control in Australia, the abundance of arthropods, predators and parasitoids as well as potential pests, was observed to be higher in all native cover crops (Danne et al., 2010). The comparison of sown and spontaneous cover crops generated varied results. Regarding Anagrus parasitism rate, in an experiment in Italy, it was higher in sown cover crops (Muscas et al., 2017) than in spontaneous covers. However, under these conditions, an increase in the abundance and biodiversity of syrphids was observed in spontaneous vegetation compared to sown cover crops (Pétremand et al., 2017).

SOIL GAS EMISSIONS

Like most economic sectors, agriculture contributes to greenhouse gas (GHG) emissions. However, agriculture can also participate as a sink for gas emission storage by means of carbon sequestration in the soil. As the use of cover crops increases SOC, the installation of a cover crop can contribute to mitigating CO₂ emissions.

In a comparative study of spontaneous and Hordeum vulgare cover crops, the emissions were higher after tillage than in mown treatments where plant biomass was incorporated to the soil (Steenwerth et al., 2010). In the same way, Bogunovic et al. (2017) observed that higher CO₂ emissions were found in annual tillage treatment compared to tilling the soil every two years. Lower emissions were observed under continuous no-tillage treatment, indicating that the cover crop management has more influence on CO₂ emissions than the cover crop itself. When the cover crop was annually mown and tilled, a C loss was observed, while a barley cover crop under minimum tillage (superficial tillage every two years) accumulated 1.12 Mg CO₂ ha⁻¹ year⁻¹ (Steenwerth et al., 2010). However, higher N₂O emissions were detected when leguminous cover crops were mowed and left on the soil surface, under the row or between lines, compared to the incorporation of residues into the soil via conventional tillage (Garland et al., 2011), although these increased emissions relate to the nitrogen that had been previously fixed by the cover crop from the atmosphere.

The dynamics of C sequestration and emission change along the season in cover-cropped vineyards, and at some points, due to their higher biological activity, increased emissions when the soil is moist (Peregrina, 2016; Steenwerth et al., 2010). Nevertheless, on a yearly or long-term basis, the presence of cover crops contributes very actively to C sequestration through the increase in SOC.

CONCLUSIONS

The systematic review performed has allowed a complete synthesis of the knowledge generated in the last two decades regarding the influence of cover crops on soil characteristics and biodiversity in vineyards. This first part is focused on soil characteristics and environment-related issues, whereas their effect on agronomic performance will be presented in the second part of this work.

As part of this wide-scope analysis, it can be concluded that using cover crops has a positive effect on increasing SOC and thus in reducing greenhouse gases in the atmosphere. Covers crops do not, in general, constitute a major competition for nutrients to the vines except for nitrogen when grass covers are used. On the contrary, legume cover crops generally increase N in the soil, although the availability of this for plants is not immediate.

Cover crops improve aggregate stability and reduce erosion. Likewise, there is an increase in biodiversity, both in soil biodiversity and activity, as well as in populations of arthropods, birds and small mammals.

Both the SOC increases in the long run and the erosion reduction are greater when the cover is formed by grasses, the results being more variable when the used cover is formed by legumes.

There are other aspects where the implication of establishing a cover crop is more variable, generally affected by soil and climate characteristics. This review constitutes a tool that can help to have a preliminary idea on what could happen under certain growing conditions, as peer-reviewed scientific literature has been revised, and some characteristics of the vineyards studied in each article are provided.
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REFERENCES

Abad, J., Hermoso de Mendoza, I., Marin, D., Orcaray, L., & Santesteban, L. G. (2021). Cover crops in viticulture. A systematic review (2): Implications on vineyard agronomic performance. OENO One, 55(2). https://doi.org/10.20870/enoone.2021.55.2.4481

Agnelli, A., Bol, R., Trumbore, S. E., Dixon, L., Cocco, S., & Corti, G. (2014). Carbon and nitrogen in soil and vine roots in harrowed and grass-covered vineyards. Agriculture, Ecosystems and Environment, 193, 70 - 82. https://doi.org/10.1016/j.agee.2014.04.023

Bagagiolo, G., Biddoccu, M., Rabino, D., & Cavallo, E. (2018). Effects of rows arrangement, soil management, and rainfall characteristics on water and soil losses in Italian sloping vineyards. Environmental Research, 166, 690 - 704. https://doi.org/10.1016/j.envres.2018.06.048

Barić, B., Kontić, J. K., & Pajač, I. P. (2008). Influence of the green cover as ecological soil cover on the vineyard insect complex. Cereal Research Communications, 36(SUPPL. 5), 35 - 38. https://doi.org/10.1556/CRC.36.2008

Barrio, I. C., Villafuerte, R., & Tortosa, F. S. (2012). Can cover crops reduce rabbit-induced damages in vineyards in southern Spain? Wildlife Biology, 18(1), 88 - 96. https://doi.org/10.2981/10-110

Bartoli, F., & Dousset, S. (2011). Impact of organic inputs on wettability characteristics and structural stability in silty vineyard topsoil. European Journal of Soil Science, 62(2), 183 - 194. https://doi.org/10.1111/j.1365-2389.2010.01337.x

Begum, M., Gurr, G. M., Wratten, S. D., Hedberg, P. R., & Nicol, H. I. (2006). Using selective food plants to maximize biological control of vineyard pests. Journal of Applied Ecology, 43(3), 547 - 554. https://doi.org/10.1111/j.1365-2664.2006.01168.x

Belmonte, S. A., Celi, L., Stanchi, S., Said-Pullicino, D., Zanini, E., & Bonifacio, E. (2016). Effects of permanent grass versus tillage on aggregation and organic matter dynamics in a poorly developed vineyard soil. Soil Research, 54(7), 797 - 808. https://doi.org/10.1071/SR15277

Belmonte, S. A., Celi, L., Stahel, R. J., Bonifacio, E., Zanini, E., & Steenwerth, K. L. (2018). Effect of Long-Term Soil Management on the Mutual Interaction Among Soil Organic Matter, Microbial Activity and Aggregate Stability in a Vineyard. Pedosphere, 28(2), 288 - 298. https://doi.org/10.1016/S1002-0160(18)60015-3

Biddoccu, M., Ferraris, S., Opsi, F., & Cavallo, E. (2015). Effects of Soil Management on Long-Term Runoff and Soil Erosion Rates in Sloping Vineyards. Engineering Geology for Society and Territory - Volume I: Climate Change and Engineering Geology. https://doi.org/10.1007/978-3-319-09300-0_30

Biddoccu, M., Ferraris, S., Opsi, F., & Cavallo, E. (2016). Long-term monitoring of soil management effects on runoff and soil erosion in sloping vineyards in Alto Monferrato (North-West Italy). Soil and Tillage Research, 155, 176 - 189. https://doi.org/10.1016/j.still.2015.07.005

Biddoccu, M., Opsi, F., & Cavallo, E. (2014). Relationship between runoff and soil losses with rainfall characteristics and long-term soil management practices in a hilly vineyard (Piedmont, NW Italy). Soil Science and Plant Nutrition, 60(1), 92 - 99. https://doi.org/10.1080/00380768.2013.862488

Bogunovic, I., Bilandzija, D., Andabaka, Z., Stupic, D., Rodrigo Comino, J., Cacic, M., Brezinscak, L., Maletic, E., & Pereira, P. (2017). Soil compaction under different management practices in a Croatian vineyard. Arabian Journal of Geosciences, 10(15). https://doi.org/10.1007/s12517-017-3105-y

Brunetto, G., Lorenzini, F., Ceretta, C. A., Ferreira, P. A. A., Couto, R. R., De Conti, L., Ciotta, M. N., Kulmann, M., Scheider, R. O., Somavilla, L. M., Tiecher, T. L., Giocomini, S., Bastos de Melo, G. W., & Carranca, C. L. V. A. F. (2017). Contribution of mineral N to young grapevine in the presence or absence of cover crops. Journal of Soil Science and Plant Nutrition, 17(3), 570 - 580. https://doi.org/10.4067/S0718-95162017000300002

Buchholz, J., Querner, P., Paredes, D., Bauer, T., Strauss, P., Guernion, M., Cluzeau, D., Burel, F., Kratschemer, S., Winter, S., Potthoff, & M., Zaller, J. G. (2017). Soil biota in vineyards are more influenced by plants and soil quality than by tillage intensity or the surrounding landscape. Scientific Reports, 7(1). https://doi.org/10.1038/s41598-017-17601-w

Buehler, R., Bosco, L., Arlettaz, R., & Jacot, A. (2017). Nest site preferences of the Woodlark (Lullula arborea) and its association with artificial nest predation. Acta Oecologica, 78, 41 - 46. https://doi.org/10.1016/j.actao.2016.12.004

Burgio, G., Marchesini, E., Reggiani, N., Montepaone, G., Schiatti, P., & Sommaggio, D. (2016). Habitat management of organic vineyard in Northern Italy: The role of cover plants management on arthropod functional biodiversity. Bulletin of Entomological Research, 106(6), 759 - 768. https://doi.org/10.1017/s0007485316000493

Celette, F., Findeling, A., & Gary, C. (2009). Competition for nitrogen in an unfertilized intercropping system: The case of an association of grapevine and grass cover in a Mediterranean climate. European Journal of Agronomy, 30(1), 41 - 51. https://doi.org/10.1016/j.eja.2008.07.003
Centinari, M., Vanden Heuvel, J. E., Goebel, M., Smith, M. S., & Bauerle, T. L. (2016). Root-zone management practices impact above and belowground growth in Cabernet Franc grapevines. *Australian Journal of Grape and Wine Research*, 22(1), 137 - 148. https://doi.org/10.1111/ajgw.12162

Daane, K. M., Hogg, B. N., Wilson, H., & Yokota, G. Y. (2018). Native grass ground covers provide multiple ecosystem services in Californian vineyards. *Journal of Applied Ecology*, 55(5), 2473 - 2483. https://doi.org/10.1111/1365-2664.13145

Danne, A., Thomson, L. J., Sharley, D. J., Penfold, C. M., & Hoffmann, A. A. (2010). Effects of native grass cover crops on beneficial and pest invertebrates in Australian vineyards. *Environmental Entomology*, 39(3), 970 - 978. https://doi.org/10.1093/ENV09144

Devetter, L. W., Dilley, C. A., & Nonnecke, G. R. (2015). Mulches reduce weeds, maintain yield, and promote soil quality in a continental-climate vineyard. *American Journal of Enology and Viticulture*, 66(1), 54 - 64. https://doi.org/10.5344/ajev.2014.14064

Duarte, J., Farfán, M. A., Fa, J. E., & Vargas, J. M. (2014). Soil conservation techniques in vineyards increase passerine diversity and crop use by insectivorous birds. *Bird Study*, 61(2), 193 - 203. https://doi.org/10.1080/00063657.2014.901294

English-Loeb, G., Rheinads, M., Martinson, T., & UGINE, T. (2003). Influence of flowering cover crops on *Anagrus* parasitoids (Hymenoptera: Mymaridae) and *Erythroneura* leafhoppers (Homoptera: Cicadellidae) in New York vineyards. *Agricultural and Forest Entomology*, 5(2), 173 - 181. https://doi.org/10.1046/j.1461-9563.2003.00179.x

Ferreira, C. S. S., Keizer, J. J., Santos, L. M. B., Serpa, D., Silva, V., Cerqueira, M., Ferreira, A. J. D., & Abrantes, N. (2018). Runoff, sediment and nutrient exports from a Mediterranean vineyard under integrated production: An experiment at plot scale. *Agriculture, Ecosystems and Environment*, 256, 184 - 193. https://doi.org/10.1016/j.agee.2018.01.015

Fourie, J. C., Agenbag, G. A., & Louw, P. J. E. (2007). Cover crop management in a Sauvignon blanc/Reyno vineyard in the Semi-Arid Olifants River Valley, South Africa. 3. effect of different cover crops and cover crop management practices on the organic matter and macro-nutrient contents of a Sandy Soil. *South African Journal of Enology and Viticulture*, 28(2), 92 - 100. https://doi.org/10.21548/28-2-1464

Franin, K., Kušter, G., & Šišeta, F. (2016). Fauna of ground-dwelling arthropods in vineyards of Zadar County (Croatia) | Fauna prizemnih člankonožaca u vinogradima Zadarske županije (Hrvatska). *Poljoprivreda*, 22(2), 50 - 56. https://doi.org/10.18047/poljo.22.2.8

García-Díaz, A., Allas, R. B., Cristina, L., Cerdà, A., Pereira, P., & Novara, A. (2016). Carbon input threshold for soil carbon budget optimization in eroding vineyards. *Geoderma*, 271, 144 - 149. https://doi.org/10.1016/j.geoderma.2016.02.020

García-Díaz, A., Bienes, R., Sastre, B., Novara, A., Cristina, L., & Cerdà, A. (2017). Nitrogen losses in vineyards under different types of soil groundcover. A field runoff simulator approach in central Spain. *Agriculture, Ecosystems and Environment*, 236, 256 - 267. https://doi.org/10.1016/j.agee.2016.12.013

García-Díaz, A., Marqués, M. J., Sastre, B., & Bienes, R. (2018). Labile and stable soil organic carbon and physical improvements using groundcovers in vineyards from central Spain. *Science of the Total Environment*, 621, 387 - 397. https://doi.org/10.1016/j.scitotenv.2017.11.240

Garcia, L., Celette, F., Gary, C., Ripoche, A., Valdés-Gómez, H., & Metay, A. (2018). Management of service crops for the provision of ecosystem services in vineyards: A review. *Agriculture, Ecosystems and Environment*, 251, 158 - 170. https://doi.org/10.1016/j.agee.2017.09.030

Garland, G. M., Saddick, E., Burger, M., Horwath, W. R., & Six, J. (2011). Direct N2O emissions following transition from conventional till to no-till in a cover cropped Mediterranean vineyard (*Vitis vinifera*). *Agriculture, Ecosystems and Environment*, 141(1 - 2), 234 - 239. https://doi.org/10.1016/j.agee.2011.02.017

Gonçalves, F., Carlos, C., Aranha, J., & Torres, L. (2018). Does habitat heterogeneity affect the diversity of epigaeic arthropods in vineyards? *Agricultural and Forest Entomology*, 20(3), 366 - 379. https://doi.org/10.1111/afe.12270

Gonçalves, F., Zina, V., Carlos, C., Crespo, L., Oliveira, I., & Torres, L. (2017). Ants (Hymenoptera: Formicidae) and Spiders (Araneae) Co-occurring in the Ground of Vineyards from Douro Demarcated Region. *Sociobiology*, 64(4), 404 - 416. https://doi.org/10.13102/sociobiology.v64i4.1934

Gontier, L., Caboulet, D., & Lhoutellier, C. (2014). Assessment of the agronomic value of sewage sludge compost applied on wine-growing soils. *Acta Horticulturae* (Vol. 1018). https://doi.org/10.17660/ActaHortic.2014.1018.26

Irvin, N. A., Bistline-East, A., & Hoddle, M. S. (2016). The effect of an irrigated buckwheat cover crop on grape vine productivity, and beneficial insect and grape pest abundance in southern California. *Biological Control*, 93, 72 - 83. https://doi.org/10.1016/j.biocontrol.2015.11.009

Irvin, N. A., Hagler, J. R., & Hoddle, M. S. (2018). Measuring natural enemy dispersal from cover crops in a California vineyard. *Biological Control*, 126, 15 - 25. https://doi.org/10.1016/j.biocontrol.2018.07.008
Judit, G., Gábor, Z., Ádám, D., Tamás, V., & György, B. (2011). Comparison of three soil management methods in the Tokaj wine region. *Mitteilungen Klosterteinburg*, 61(4), 187 - 195.

Klodd, A. E., Eissenstat, D. M., Wolf, T. K., & Centini, M. (2016). Coping with cover crop competition in mature grapevines. *Plant and Soil*, 400(1 - 2), 391 - 402. https://doi.org/10.1007/s11104-015-2748-2

Krnic Martinic, M., Pieper, D., Glatt, A., & Puljak, L. (2019). Definition of a systematic review used in overviews of systematic reviews, meta-epidemiological studies and textbooks. *BMC Medical Research Methodology*, 19(1), 1 - 12. https://doi.org/10.1186/s12874-019-0855-0

Likar, M., Stres, B., Rusjan, D., Potisek, M., & Regvar, M. (2017). Ecological and conventional viticulture gives rise to distinct fungal and bacterial microbial communities in vineyard soils. *Applied Soil Ecology*, 113, 86 - 95. https://doi.org/10.1016/j.apseol.2017.02.007

López-Piñeiro, A., Muñoz, A., Zamora, E., & Ramírez, M. (2013). Influence of the management regime and phenological state of the vines on the physicochemical properties and the seasonal fluctuations of the microorganisms in a vineyard soil under semi-arid conditions. *Soil and Tillage Research*, 126, 119 - 126. https://doi.org/10.1016/j.still.2012.09.007

Mackie, K. A., Schmidt, H. P., Müller, T., & Kandeler, E. (2014). Cover crops influence soil microorganisms and phytoextraction of copper from a moderately contaminated vineyard. *Science of the Total Environment*, 500 - 501, 34 - 43. https://doi.org/10.1016/j.scitotenv.2014.08.091

Marques, M. J., García-Muñoz, S., Muñoz-Organero, G., & Bienes, R. (2010). Soil conservation beneath grass cover in hillside vineyards under mediterranean climatic conditions (MADRID, SPAIN). *Land Degradation and Development*, 21(2), 122 - 131. https://doi.org/10.1002/ldr.915

Mattii, G. B., Storchi, P., & Ferrini, F. (2005). Effects of soil management on physiological, vegetative and reproductive characteristics of Sangiovese grapevine. *Advances in Horticultural Science*, 19(4), 198 - 205.

Messiga, A. J., Sharifi, M., Hammermeister, A., Gallant, K., Fuller, K., & Tango, M. (2015). Soil quality response to cover crops and amendments in a vineyard in Nova Scotia, Canada. *Scientia Horticulturae*, 188, 6 - 14. https://doi.org/10.1016/j.scienta.2015.02.041

Minuz, R. L., Isidoro, N., Casavecchia, S., Burgio, G., & Riolo, P. (2013). Sex-dispersal differences of four phloem-feeding vectors and their relationship to wild-plant abundance in vineyard agroecosystems. *Journal of Economic Entomology*, 106(6), 2296 - 2309. https://doi.org/10.1603/EC13244

Morvan, X., Naisse, C., Malam Issa, O., Desprats, J. F., Combau, A., & Cerdan, O. (2014). Effect of ground-cover type on surface runoff and subsequent soil erosion in Champagne vineyards in France. *Soil Use and Management*, 30(3), 372 - 381. https://doi.org/10.1111/sum.12129

Muscas, E., Cocco, A., Mercenaro, L., Cabras, M., Lentini, A., Porqueddu, C., & Nieddu, G. (2017). Effects of vineyard floor cover crops on grapevine vigor, yield, and fruit quality, and the development of the vine mealybug under a Mediterranean climate. *Agriculture, Ecosystems and Environment*, 237, 203 - 212. https://doi.org/10.1016/j.agee.2016.12.035

Napol, M., Marta, A. D., Zanchi, C. A., & Orlandini, S. (2017). Assessment of soil and nutrient losses by runoff under different soil management practices in an Italian hilly vineyard. *Soil and Tillage Research*, 168, 71 - 80. https://doi.org/10.1016/j.still.2016.12.011

Nicholls, C. I., Altieri, M. A., & Ponti, L. (2008). Enhancing plant diversity for improved insect pest management in Northern California organic vineyards. *Acta Horticulturae* (Vol. 785). https://doi.org/10.17660/ActaHortic.2008.785.32

Nicholls, C. I., Parrella, M. P., & Altieri, M. A. (2000). Reducing the abundance of leafhoppers and thrips in a northern California organic vineyard through maintenance of full season floral diversity with summer cover crops. *Agricultural and Forest Entomology*, 2(2), 107 - 113. https://doi.org/10.1046/j.1461-9563.2000.00054.x

Novara, A., Cristina, L., Guaitoli, F., Santoro, A., & Cerdà, A. (2013). Managing soil nitrate with cover crops and buffer strips in Sicilian vineyards. *Solid Earth*, 4(2), 255 - 262. https://doi.org/10.5194/se-4-255-2013

Novara, A., Cristina, L., Saladino, S. S., Santoro, A., & Cerdà, A. (2011). Soil erosion assessment on tillage and alternative soil managements in a Sicilian vineyard. *Soil and Tillage Research*, 117, 140 - 147. https://doi.org/10.1016/j.still.2011.09.007

Ovalle, C., Del Pozo, A., Lavin, A., & Hirzel, J. (2007). Cover crops in vineyards: Performance of annual forage legumes and pastures in a vineyard under different climatic conditions. *Agricultura Tecnica*, 67(4), 384 - 392. https://doi.org/10.4067/S0365-28072007000400006

Peoples, M. B., Brockwell, J., Herridge, D. F., Rochester, I. J., Alves, B. J., Uruquiaga, S., Boddey, R. M., Dakora, F. D., Bhattarai, S., Maskey, S. L., Sampet, C., Rerkasem, B., Khan, D. F., Hauggaard-Nielsen, H., & Jensen, E. B. (2009). Review article. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. *SYABIOISIS*, 48, 1 - 17. https://doi.org/10.1007/BF03179980
Peregrina, F. (2016). Surface Soil Properties Influence Carbon Oxide Pulses After Precipitation Events in a Semiarid Vineyard Under Conventional Tillage and Cover Crops. *Pedosphere*, 26(4), 499 - 509. https://doi.org/10.1016/S1002-0160(15)60060-1

Peregrina, F., Larrieta, C., Ibáñez, S., & García-Escudero, E. (2010). Labile organic matter, aggregates, and stratification ratios in a semiarid vineyard with cover crops. *Soil Science Society of America Journal*, 74(6), 2120 - 2130. https://doi.org/10.2136/sssaj2010.0081

Peregrina, F., Pérez-Álvarez, E. P., & García-Escudero, E. (2014). The short term influence of aboveground biomass cover crops on C sequestration and β-glucosidase in a vineyard ground under semiarid conditions. *Spanish Journal of Agricultural Research*, 12(4), 1000 - 1007. https://doi.org/10.5424/sjar/2014124-5818

Pérez-Álvarez, E. P., García-Escudero, E., & Peregrina, F. (2015a). Soil nutrient availability under Cover Crops: Effects on vines, must, and wine in a Tempranillo Vineyard. *American Journal of Enology and Viticulture*, 66(3), 311 - 320. https://doi.org/10.5344/aje.2015.14092

Pérez-Álvarez, E. P., Garde-Cerdán, T., Santamaría, P., García-Escudero, E., & Peregrina, F. (2015b). Influence of two different cover crops on soil N availability, N nutritional status, and grape yeast-assimilable N (YAN) in a cv. Tempranillo vineyard. *Plant and Soil*, 390(1 - 2), 143 - 156. https://doi.org/10.1007/s11104-015-2387-7

Pérez-Álvarez, E. P., Pérez-Sotés, J. L., García-Escudero, E., & Peregrina, F. (2013). Cover Crop Short-Term Effects on Soil NO₃⁻N Availability, Nitrogen Nutritional Status, Yield, and Must Quality in a Calcareous Vineyard of the AOC Rioja, Spain. *Communications in Soil Science and Plant Analysis*, 44(1 - 4), 711 - 721. https://doi.org/10.1080/00103624.2013.748122

Pétrremand, G., Speight, M. C. D., Fleury, D., Castella, E., & Delabays, N. (2017). Hoverfly diversity supported by vineyards and the importance of ground cover. *BULLETIN OF INSECTOLOGY*, 70(1), 147 - 155.

Pou, A., Gulías, J., Moreno, M., Tomás, M., Medrano, H., & Cifre, J. (2011). Cover cropping in *Vitis vinifera* L. cv. Manto Negro vineyards under Mediterranean conditions: Effects on plant vigour, yield and grape quality. *Journal International Des Sciences Horticulturae*, 45(4), 223 - 234. https://doi.org/10.20870/oeno-one.2011.45.4.1501

Ramazzotti, S., Stagnari, F., & Pisante, M. (2008). Integrated soil and water management for vineyards in southern Italy: A case study. *Italian Journal of Agronomy*, 3(3), 117 - 118.

Renaud, A., Poinso-Balagué, N., Cortet, J., & Le Petit, J. (2004). Influence of four soil maintenance practices on Collomella communities in a Mediterranean vineyard. *Pedobiologia*, 48(5 - 6), 623 - 630. https://doi.org/10.1016/j.pedobi.2004.07.002

Rodriguez-Lovelle, B., Soyer, J. P., & Molot, C. (2000). Nitrogen availability in vineyard soils according to soil management practices. effects on vine. *Acta Horticulturae* (Vol. 526). https://doi.org/10.17660/ActaHortic.2000.526.29

Ruiz-Colmenero, M., Bienes, R., Eldridge, D. J., & Marques, M. J. (2013). Vegetation cover reduces erosion and enhances soil organic carbon in a vineyard in the central Spain. *Catena*, 104, 153 - 160. https://doi.org/10.1016/j.catena.2012.11.007

Ruiz-Colmenero, M., Bienes, R., & Marques, M. J. (2011). Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. *Soil and Tillage Research*, 117, 211 - 223. https://doi.org/10.1016/j.still.2011.10.004

Sandanayaka, W. R. M., Davis, V. A., & Jesson, L. K. (2018). Mealybug preference among clover cultivars: Testing potential groundcover plants to dissociate mealybugs from grapevines. *New Zealand Plant Protection*, 71, 248 - 254. https://doi.org/10.30843/nzpp.2018.71.138

Sanguankeo, P. P., & León, R. G. (2011). Weed management practices determine plant and arthropod diversity and seed predation in vineyards. *Weed Research*, 51(4), 404 - 412. https://doi.org/10.1111/j.1365-3180.2011.00853.x

Smith, I. M., Hoffmann, A. A., & Thomson, L. J. (2015). Ground cover and floral resources in shelterbelts increase the abundance of beneficial hymenopteran families. *Agricultural and Forest Entomology*, 17(2), 120 - 128. https://doi.org/10.1111/afe.12086

Steenwerth, K., & Belina, K. M. (2008). Cover crops and cultivation: Impacts on soil N dynamics and microbiological function in a Mediterranean vineyard agroecosystem. *Applied Soil Ecology*, 40(2), 370 - 380. https://doi.org/10.1016/j.apsoll.2008.06.004

Steenwerth, K., & Guerra, B. (2012). Influence of floor management technique on grapevine growth, disease pressure, and juice and wine composition: A review. *American Journal of Enology and Viticulture*, 63(2), 149 - 164. https://doi.org/10.5344/ajev.2011.10001

Steenwerth, K. L., Pierce, D. L., Carlisle, E. A., Spencer, R. G. M., & Smart, D. R. (2010). A vineyard agroecosystem: Disturbance and precipitation affect soil respiration under mediterranean conditions. *Soil Science Society of America Journal*, 74(1), 231 - 239. https://doi.org/10.2136/sssaj2008.0346

Sulas, L., Mercenaro, L., Campesi, G., & Nieddu, G. (2017). Different cover crops affect nitrogen fluxes in mediterranean vineyard. *Agronomy Journal*, 109(6), 2579 - 2585. https://doi.org/10.2134/agronj2017.05.0283

Usón, A., Espinosa, E., & Poch, R. M. (1998). Effectivity of soil conservation practices in vineyard soils from Catalonia region, Spain. *International Agrophysics*, 12(3), 155 - 165.
Varga, P., Májer, J., Jahnke, G. G., Németh, C., Szoke, B., Sárdi, K., Varga, Z., Kocsis, L., & Salamon, B. (2012). Adaptive Nutrient Supply and Soil Cultivation Methods in the Upper Zone of Hillside Vineyards. *Communications in Soil Science and Plant Analysis, 43*(1 - 2), 334 - 340. https://doi.org/10.1080/00103624.2012.641463

Virto, I., Imaz, M. J., Fernández-Ugalde, O., Urrutia, I., Enrique, A., & Bescansa, P. (2012). Soil quality evaluation following the implementation of permanent cover crops in semi-arid vineyards. *Organic matter, physical and biological soil properties | Evaluación de la calidad del suelo tras la implantación de cubiertas permanentes en viñedos de. Spanish Journal of Agricultural Research, 10*(4), 1121 - 1132. https://doi.org/10.5424/sjar/2012104-613-11

Vogelweith, F., & Thiéry, D. (2017). Cover crop differentially affects arthropods, but not diseases, occurring on grape leaves in vineyards. *Australian Journal of Grape and Wine Research, 23*(3), 426 - 431. https://doi.org/10.1111/ajgw.12290

Vrsic, S., Ivancic, A., Pulko, B., & Valdhuber, J. (2011). Effect of soil management systems on erosion and nutrition loss in vineyards on steep slopes. *Journal of Environmental Biology, 32*(3), 289 - 294.

Wilson, H., Miles, A. F., Daane, K. M., & Altieri, M. A. (2017). Landscape diversity and crop vigor outweigh influence of local diversification on biological control of a vineyard pest. *Ecosphere, 8*(4). https://doi.org/10.1002/ecs2.1736

Wilson, H., Wong, J. S., Thorp, R. W., Miles, A. F., Daane, K. M., & Altieri, M. A. (2018). Summer Flowering Cover Crops Support Wild Bees in Vineyards. *Environmental Entomology, 47*(1), 63 - 69. https://doi.org/10.1093/ee/nvx197

Zehetner, F., Djukic, I., Hofmann, R., Kühnen, L., Rampazzo-Todorovic, G., Gerzabek, M. H., & Soja, G. (2015). Soil organic carbon and microbial communities respond to vineyard management. *Soil Use and Management, 31*(4), 528 - 533. https://doi.org/10.1111/sum.12204