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N_2O, CO_2, Production, and C Sequestration in Vineyards: a Review

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Abstract Even if it is less polluting than other farm sectors, grape growing management has to adopt measures to mitigate greenhouse gas (GHG) emissions and to preserve the quality of grapevine by-products. In viticulture, by land and crop management, GHG emissions can be reduced through adjusting methods of tillage, fertilizing, harvesting, irrigation, vineyard maintenance, electricity, natural gas, and transport until wine marketing, etc. Besides CO_2, nitrous oxide (N_2O) and methane (CH_4), released from fertilizers and waste/wastewater management are produced in vineyards. As the main GHG in vineyards, N_2O can have the same harmful action like large quantities of CO_2. Carbon can be found in grape leaves, shoots, and even in fruit pulp, roots, canes, trunk, or soil organic matter. C sequestration in soil by using less tillage and tractor passing is one of the efficient methods to reduce GHG in vineyards, with the inconvenience that many years are needed for detectable changes. In the last decades, among other methods, cover crops have been used as one of the most efficient way to reduce GHG emissions and increase fertility in vineyards. Even if we analyze many references, there are still limited information on practical methods in reducing emissions of greenhouse gases in viticulture. The aim of the paper is to review the main GHG emissions produced in vineyards and the approached methods for their reduction, in order to maintain the quality of grapes and other by-products.

Keywords Carbon · Cover crops · GHG emissions · Grapevine · Nitrous oxide · C sequestration

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1 Introduction

Sources of GHG emissions of the world are primary electricity production, transportation, industry, commercial and residential, agriculture, land use, and forestry (Oertel et al. 2016). CO_2 emissions in the atmosphere from fossil fuel increased by about 90% since 1970; current emissions nowadays would need 1.2 Earth ecosystems to be completely absorbed (Chiarawipa et al. 2013). Carbon content of the Earth's is about two times higher than that in the atmosphere (0.04%), and three times higher than that the accumulated in vegetation (Batjes and Dijkshoorn 1999). Europe's soils are huge carbon reservoirs, containing around 75 billion tonnes (Yigini and Panagos 2016).

Carbon can be found in soil as organic or inorganic forms. Organic carbon is extremely important for soil to provide edaphic ecosystem services, soil "health," or soil fertility (Smith and Wigley 2000). If more CO_2 is stored in the soil organic matter and biomass, it will decrease the amount from the atmosphere and consequently will reduce global warming (Stavins 1999).

Carbon content in the soil is influenced mainly by climate, texture, hydrology, land use, and vegetation. Soils from natural ecosystems usually sequestrate higher carbon stocks then soils from intensive land use (Adams et al. 1993). When soil organic matter decomposes, it releases carbon dioxide (CO_2), which is the main greenhouse gas. In the atmosphere, carbon dioxide is taken up by green plants, and then, it is combined with water to make simple carbohydrate molecules—sugars, namely glucose (Gonzalez-Sanchez et al. 2012).

The main GHG emissions from agriculture (14–24% of global emissions) results from soils (about one half of agricultural emissions), enteric fermentation (CH_4 emissions in ruminants and management of animal manure, accounting for one third), and manure management (around one sixth). Minor contributors are rice cultivation and burning of agricultural residues (Bass 2016). Mitigation in agricultural GHG emissions may be reduced by lowering the livestock number and the application of nitrogen fertilizers, adopting better farming practices, and more efficient manure management (Franks and Hadingham 2012).

In the future, the increasing Earth population will need more food, which means a 46% increase of agricultural emissions by 2030 (from 5.6 in the present to 8.2 billion tonnes of CO_2 equivalent). This high percentage can be lowered through limiting waste and utilizing a larger part of food produced (Capros et al. 2016). In vineyards, the main sources of GHG emissions are tillage, nitrogen fertilizers, maintenance of the vineyard, grape juice fermentation, electricity and natural gas (100 g CO_2 bottle of wine^{-1}), and the transport until the wine marketing (Colman and Päster 2007). Grape growing and the wine industry are dependent on carbon dioxide fixation from the atmosphere through photosynthesis for biomass production, but at the same time, this also emits CO_2 back in the atmosphere (Colman and Päster 2007).

During grape juice fermentation, aside from CO_2, amyl alcohol, *n*-propanol, iso-butanol, and a variety of esters are released into the air (Soja et al. 2010). Wine grape quality is largely influenced by climate change. Two- or three-degree air temperature fluctuation is enough to change the grape quality and the type of wine (Jones et al. 2005). Therefore, it is very important that grape growers and winemakers adopt measures to mitigate greenhouse gas emissions on the whole chain of production. GHG emissions in viticulture are smaller compared with other agricultural sectors, but detailed surveys are missing, because most studies are split into plant and animal production.

The objective of the paper is to update and review the main GHG emissions, providing information concerning practical methods for their mitigation in vineyards. The literature review covers N_2O, CO_2 production, and C sequestration in vineyards and discusses how viticulture can contribute to mitigate GHG emissions; even grape growing is a small contributor to the global "problem."

2 N_2O Production

In vineyard, N_2O is mainly produced which can act as GHG, and even in small amounts, it can cause the same global warming as large quantities of CO_2 (Cassman et al. 2002). According to IPCC (International Panel on Climate Change) protocol, 1 kg of N_2O is equal to 300 kg CO_2 (Carlisle et al. 2009). N_2O emissions from soil are influenced by the labile stock of C (green manure, weeds, stubble incorporated into the soil), nitrate amount, and moisture in the soil. The higher the levels of labile C and nitrate (NO_3^-) in the soil are, the higher the N_2O emissions are in the atmosphere (Treeby et al. 2004).

Nitrogen fertilizers (nitrate, ammonium, green manure, pomace, mulch, cane pruning, cover crops), applied in vineyards, are converted and become an important source of N_2O, N_2, or NH_3 by nitrification and denitrification, if the fertilizers are in excess for plants or are applied in the wrong period (high humidity) and place (compacted soils) (Bremner 1997; Mosier et al. 2005).

Application of large amounts of N fertilizers in vineyards increases the C sequestration in biomass of vines which is added in the soil year after year (Bouwman et al. 2002).

Extensive studies have shown that N_2O production in annual cropping is strong correlated with soil organic matter, tillage, fertilizer type, amount, or method of delivery (Lemke et al. 2007; Venterea et al. 2005; Scheer et al. 2008; Sanchez-Martin et al. 2008). Regarding woody perennial crops, few studies can be found concerning N_2O production. Gregory et al. (2005), after a large set of observation, report that perennial crops produce lower N_2O emissions than annual cropping systems. In wine grapes, minimizing N_2O emissions may be challenging because generally little fertilizer is used; to further decrease emissions of N_2O may be difficult (Carlisle et al. 2009).

An alternative for nitrogen supply can be cover crops and organic fertilizers, but experts in soil and grape growing believe that more information is needed about the relationship of N application–N_2O production–C sequestration (Gomes et al. 2009).

Organic matter decomposition is the main source of nitrogen, which is slowly released from the soil and the production increase is equal to the soil temperature (Hawk and Martinson 2007). The amount of organic matter in the soil increases as moisture increases due to plant growth (Paradelo et al. 2016). In anaerobic soils, optimal conditions for microbial production of N_2O are developed. An intense microbial activity will increase decomposition of organic matter and consequently CO2 emissions, especially in wet and warm soils (Alluvione et al. 2010).

During tillage, emissions of CO_2 and N_2O increases when soil aggregates are broken and microbes are free to consume organic matter. Conventional tillage reduces the soil's capacity to store carbon, while no-tillage (vineyard floor management with perennial or annual cover crop species) means, first of all, no GHG emissions from tractors, an increased possibility of soil to store carbon, and organic matter protected from decomposition (Petersen et al. 2011). Depending on terroir, high amounts of carbon from soil can lead to higher emissions of N_2O which dissipate the benefit of carbon sequestration (Beare et al. 1994).

In the opinion of Suddick et al. (2011), the tillage effect on N_2O emission in vineyards is not sufficiently researched and clear. However, in a vineyard from Northern California, it was found that standard tillage released less N_2O from soil (0.13 ± 0.021 kg N_2O-N ha^{-1} $season^{-1}$) compared to conservation or no-tillage (0.19 ± 0.017 kg N_2O-N ha^{-1} $season^{-1}$) (Suddick et al. 2011). Garland et al. (2011) found that the amount of N_2O emissions from conventional tillage in a vineyard is not different from that resulted in a no-till floor management. Instead, Steenwerth and Belina (2010) found in their research on bare soil (herbicide-treated) undervine a higher emission of N_2O, compared with cultivated treatment on vine row; it is supposed that weeds take from the soil the available nitrogen and decrease the stock for soil microorganisms. It is estimated that from total N fertilizers (both organic and inorganic) applied to the soil, around 1.25% is released as N_2O, but according to new studies, emission factors can range from 0.1 to 7.0% (Bouwman et al. 2002), depending on viticultural management (fertilizers, soil, climate conditions, irrigation, etc).

Although GHG emissions studies are long term, A 1-year research from a Northern California vineyard with N_2O frequent measures after different management practices (cover crop mowing followed by incorporation, fertilization, irrigation, etc), results in conventional tillage were 0.19 ± 0.017 kg N_2O-N ha^{-1} $season^{-1}$ undervine, and 0.11 ± 0.018 kg N_2O-N ha^{-1} middle row, not significantly greater than results from standard tillage 0.13 ± 0.021 kg N_2O-N ha^{-1} undervine and 0.07 ± 0.041 kg N_2O-N ha^{-1} middle row respectively. Compared with other studies in the Mediterranean area, total N_2O emissions were lower, due to the small quantities of N fertilizers, irrigation, and more efficient use of water and N (Garland et al. 2011).

Nitrogen overdoses increase vine vigor, but excess vine growth leads to rich canopies which results in low bud fertility/fruit quality, and pest/disease infestations (Hawk and Martinson 2007). The main amount of nitrogen in vines (about 75%) is stored in the roots, followed by trunks and canes, according to Bates et al.'s (2002) research with the Concord variety which needs 22.65 kg ha^{-1} $year^{-1}$ or 40 g of N $vine^{-1}$ $season^{-1}$, respectively. In the same research, it was found that the remaining nitrogen from the soil, shoots, or leaves is sequestered after harvest in canes and roots to be used in the following growing season (Bates et al. 2002).

Grape growers have to know that N_2O emissions depend on vineyard management, including soil type, amount of fertilizers, and humidity that must be correlated with climate conditions. In review literature, no major differences concerning N_2O emissions were found among conventional tillage and no-tillage floor management.

3 CO_2 Production

Relative to other crops, grape growing produces smaller CO_2 quantities and, at the same time, "consumes" CO_2 by photosynthesis (Fig. 1). There are few data concerning the vineyards' role in GHG production and carbon sequestration (Ohmart 2011) because the time required for needed research is quite long (3–5 years for factors relating to N_2O and CH_4 production to 10–20 years for long-term floor management concerning C sequestration) (Carlisle et al. 2010).

There are large discrepancies among studies due to the data accuracy, different stages of wine production, or

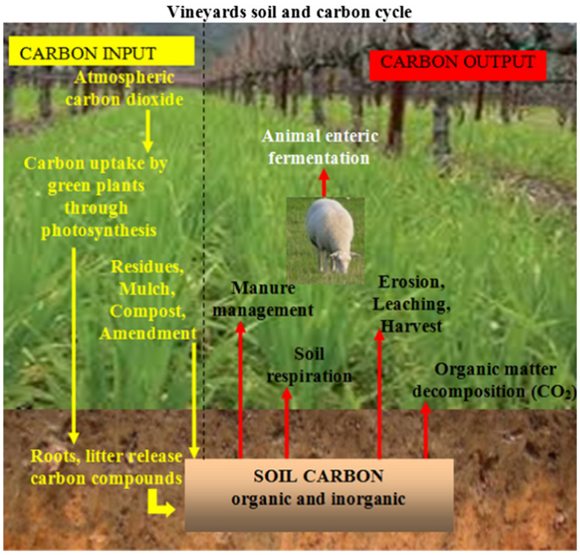

Fig. 1 Vineyard soil and carbon cycle

environment conditions. Therefore, after comparing 29 LCA (Life Cycle Assessment) articles concerning the carbon footprint (the total set of CO_2 emission) and wine production, Rugani et al. (2013) found that end-of-life process and packaging, each of them with 22%, followed by grape growing with 18%, have the highest carbon footprint. In another stage of wine production, namely vineyard planting from Italy, Bosco et al. (2011) specify 7% of carbon footprint.

The contradiction between studies can be remarked from the same stage of wine production, namely viticulture and grape growing: Soja et al. (2010) found out a level of 31% for carbon footprint, while Soosay et al. (2012) notice for the same stage 28% carbon footprint. Investigating the carbon footprint in a vineyard from South of Sardinia, Marras et al. (2015) found that for the production of 1 kg of grape, 0.39 kg CO_2 is released (most of the GHG emissions being derived from fossil fuel and soil management).

Tillage is one of the vineyard floor management with great importance to GHG emissions and balance. Tillage lead to high temperatures, thereby contributing to enhanced decomposition of organic materials (exposure to microbes), and at the same time, fossil fuel used by machineries is the main source of CO_2 emissions (Mangalassery et al. 2014). One of the most efficient ways to reduce GHG in vineyards is to decrease the fuel usage (e.g. tractor passes). Tillage more than one time/year produces more CO_2 through exposing new organic matter to decomposition (Carlisle et al. 2009). Reduced tillage often associated with cover crops enhances soil carbon stock and less GHG emission associated with tractor passing. Fuel consumption in vineyards can be reduced by eliminating tractor passing through middle row grazing with sheep (McGourty et al. 2008). No-till floor management and storage of organic matter into the soil results in carbon sequestration (Helgason et al. 2010). According to Carlisle et al. (2009) 1 l of diesel fuel used in vineyards produces 3.15 kg CO_2 ($CO_2 + N_2O + CH_4$) and 1 l of gasoline produces 2.78 kg CO_2. The organic matter of a cropland depends on the land management practices, removal of crop residues, etc.

Organic matter decomposes faster at higher temperatures; therefore, soils in warmer climates tend to contain less organic matter than those in cooler climates (Steenwerth and Belina 2008). Considering the agricultural system, Kavargiris et al. (2009) calculate the CO_2, CH_4, and N_2O emissions in conventional and organic vineyards from three different locations, and found out that GHG emissions were significantly lower in organic than that in conventional vineyards. In a research made by Colman and Päster (2007) in New Zealand vineyards, they found out that about 6.2 t ha^{-1} of dry matter is generated each year in grapevines (30% leaves, 24% shoots, 40% grapes) which is equal to 9.1 t ha^{-1} CO_2 fixation $year^{-1}$. Steenwerth et al. (2010) investigated in Cabernet Sauvignon vineyard the impacts of agricultural practices (cover cropping, tillage, mowing, resident vegetation, total C lost $year^{-1}$ by soil respiration) on soil respiration. The measurements of CO_2 emission $year^{-1}$ in the Cabernet vineyard with "under the vine' cultivation," range from 1.1 to 1.5 t C ha^{-1} fold greater than those reported by Carlisle et al. (2006) for Merlot vineyard with bare soil under vine row.

In most researchers' opinion, CO_2 emissions are significantly lower in organic than that in conventional vineyards, and undoubtedly, no-till floor management store more organic matter and enhance soil carbon stock.

4 C Sequestration

In vineyard, carbon can be found in short-lived vine parts (leaves, shoots, and fruit pulp), long-lived structures (roots, canes, trunk, etc), or soil organic matter. By mechanical pruning and thinning, or dead vine removal, large amounts of carbon stored is removed, unless the part is chipped and incorporated into the soil as organic matter, which increases the carbon sequestration (Goward 2012; Carlisle et al. 2009). Annual crops cannot be considered net carbon sinks, but perennial or permanent woody structure species, with a life of decades, like tree crops or vineyards, with plenty of pruning material left or buried in soil, could act as carbon sinks (Gianelle et al. 2015).

Carbon from soil has benefits for soil fertility and structure, improves biological and physical properties, and increases microbial activity and water holding capacity (Ludwig et al. 2011). The carbon stock depends on the soil type, climate (mainly rainfall and temperature), land management, and vegetation, and can be improved through application of manure, composts, or plant debris (Cotching 2009; Williams et al. 2011). An increase of carbon in soil does not mean a decline in the same amount of the carbon into the atmosphere (Powlson et al. 2011). According to Powlson et al. (2011), in a temperate climate area, from plant biomass incorporated into the soil after 1 year, only around one third of organic carbon is retained, while the remaining carbon is emitted into the atmosphere. Organic materials such as manure, crop residues, straw, or debris, increase the stock of organic carbon in soil, but do not transfer the carbon from the atmosphere into the soil; disposal of biosolids on land contributes to avoid emission of CH_4 and to small amounts of C sequestration (Lal 2004).

During growing season, grape berries contain the highest concentration of C (Mosier et al. 2005), but little is known about the C allocation in different permanent vine structures (roots, trunks, canes, cordons). In a study from South Africa, Munaluna and Meincken (2008) found in *Vitis vinifera* trunks a C content of 43.7%. Growing practice, environment, variety, fertilization etc., which influence vine photosynthesis, correlating with the C allocation to these structures, affect the vineyards' capacity to sequester carbon.

Grapevines develop deep roots that contribute to C sequestration; root biomass is different from one variety to another (Bauerle et al. 2008). Biomass production found on a vine is influenced by the same factors mentioned above. Williams (2000) found in the Thompson Seedless variety leaves quantity vine^{-1} from 1308 to 1554 g, and canes vine^{-1} between 1891 and 2227 g dry weight. In the same variety were found among other quantities for leaves—between 1100 and 1800 g vine^{-1} and 700–2200 g vine^{-1} dry cane (Williams et al. 1985).

Pruning biomass and thinning shoots, leaves and bunch, and often canes incorporated in the soil are a source of C sequestration, which will be lost as CO_2 after these decompose (Lal 2004). In Indian vineyards, with bare soil, after double pruning, a biomass production of leaves and canes of 4.0–5.0 t ha^{-1} and 5.0–6.0 t ha^{-1} dry fruit yield was estimated, which means that CO_2 sequestrated in the vineyards range from 18 to 22 t ha^{-1} year^{-1} (Singh et al. 2013). In a similar research, in New Zealand, from about 4.0 t ha^{1} dry matter results an equivalent of 8.0 t ha^{-1} CO_2 (Nendel and Kersebaum 2004). In an ample research made in California vineyards by Morande (2015), he estimated carbon stocks for biomass obtained during grapevine pruning, and the total C was 12.3 t ha^{-1}, of which 8.9 C ha^{-1} was derived from perennial vine, 1.7 t C ha^{-1} from canes and leaves, and 1.7 t C ha^{-1} from fruit. Carbon stocks were evaluated also in northern California vineyards by Williams et al. (2011) below and aboveground, with an average of 84.1 t C ha^{-1} and 3.0 t C ha^{-1}, respectively. The C stock in three old vineyards from China was evaluated by Chiarawipa et al. (2013); the total C content in the 18-year-old vineyard was 77.04 t ha^{-1}, while in the 10- and 5-year-old sites, it was of 66.92 t ha^{-1} and 55.41 t ha^{-1} respectively. For the total C stock in the living parts, the highest content (48.62 t ha-^{1}) was found in the 10-year-old vineyard, followed by the 5-year-old site (48.46 t ha^{-1}), and the last was the 18-year-old vine (38.72 t ha^{-1}). In another study from California vineyards, Williams et al. (2011) found on average around 87.10 t ha^{-1} C total stock. The C stock in four white and four red wine varieties was studied in vineyards from Australia by Goward (2012); results from the research show that the Cabernet Sauvignon variety has the highest C volume (3.11 kg vine^{-1}), followed by Shiraz (2.52 kg vine^{-1}), Chardonnay (2.04 kg vine^{-1}), Sauvignon Blanc (1.92 kg vine^{-1}), Merlot (1.9 kg vine^{-1}), Riesling (1.44 kg vine^{-1}), Pinot Noir (1.27 kg vine^{-1}), and Pinot Gris (0.78 kg vine^{-1}). In the same research, the C sequestrated per year which was around double in the soil (69.3% in 2012–65.6% estimated in 2020) compared with carbon stock from vine (30.7% in 2012–34.4% estimated in 2020) was evaluated. Studding the carbon sequestration and emission in four red (Shiraz, Cabernet sauvignon, Merlot, and Pinot Noir) and four white (Chardonnay, Sauvignon Blanc, Riesling, and Pinot Gris) grapevine varieties in an Australian environment, Goward (2012) found that red wine varieties store more C than white varieties. On average, Cabernet Sauvignon store the most C vine^{-1} (3.11 kg), followed by Shiraz (2.52 kg vine^{-1}) and Chardonnay (2.04 kg vine^{-1}). The lowest carbon stock per vine was found in Pinot Noir (1.27 kg vine^{-1}) and Pinot Gris (0.78 kg vine^{-1}). Results show also that in the entire vineyard, 30% of the total sequestrated C is stored in vines and the remaining 70% is found as stock in the soil.

Wolff et al. (2013) studied the carbon sequestrated in soil in a Cabernet Sauvignon vineyard (Napa Valley), utilizing three different management floors: minimum tillage (with dwarf barley crop); tillage associate with dwarf barley; and conventional tillage plus resident vegetation. The biomass (including C in fruits) obtained in 2009 was 3.43 t C^{-1} year^{-1} and 3.55 t C^{-1} year^{-1} in 2010. The C stock in the soil, from 1991–2003, remained constant, but after 7 years (2003–2010) of minimum tillage, C stock increased with 8.4% on average. Translated in C sequestrated into the soil results in 2640 kg C ha^{-1}, or 377 kg C (1,383 CO_2) removed annually from the atmosphere. In the variant with one till per year, C stock showed a low increase in the soil while conventional tillage brings no significant decline (Wolff et al. 2013). Sanderman and Baldock (2010) specified that minimum tillage and drilling have little stock organic carbon compared to multiple tractor and equipment pass in conventional cultivation. Several studies show that C sequestration can be higher in soil from no-till in heavy rainfall areas (Cotching 2009).

As regards the total carbon in vineyards (vines and soil), the highest level was found in the Cabernet Sauvignon experimental plot (42.75 t/ha) and the lowest in the Chardonnay plot (8.02 t/ha) (Goward 2012). No correlation was found between C stock in vine and soil organic carbon (SOC), which confirms the results of Williams et al.'s (2011) research. In a vineyard from Marlborough, New Zealand, Deurer et al. (2008) estimated the C stock over 15 years; the C lost on row (integrated vineyard system) in 0–0.15 m depth was around 2.4 ± 1 kg C m$^{2-1}$. Correlating with the entire vineyard area (permanent pasture middle row) equals to 12 ± 5 t C ha^{-1} for the same depth. The same research team compared the C stock from an organic vineyard headland (permanent pasture-control) and vine row. the conclusion was that, stock from vine row (8.1 ± 0.6 kg C m$^{2-1}$) was not significantly different from the headland (7.6 ± 0.9 kg C m$^{2-1}$) (Deurer et al. 2008). Differences were obtained in soil mulching under vine rows: in the 0–15 depth, with mulching soil, C stock was higher (63.5 ± 13.5 t C ha^{-1}) but not statistically significant compared with soil without mulching (49.5 ± 3.5 t C ha^{-1}). Finally, the research team considers the results very uncertain. The increase of C sequestration in soil needs many years after compost, mulch, cover crops application, or herbal plant incorporation (Longbottom and Petrie 2015).

In pruning biomass, dead vines, thinning shoots, leaves, bunch, and canes, etc., is found an important amount of carbon stored; it is advisable that all these vine parts be chipped and incorporated into soil as organic matter for C sequestration.

5 Common Solution—Cover Crops

Despite the fact that cover crops are used since Roman times in vineyards, few data are concerning their effect on soil C cycle. In the last decades, mainly after the Kyoto protocol (1997), many methods for sequestration of carbon in soil were tried, like cover crops, organic amendments, crop residues, minimum or no-tillage, improved rotations and cultivars, and double cropping (Guo and Gifford 2002; Dobrei et al. 2014). Regardless of the method, soil organic carbon changes respond slowly; for detectable changes, long-term experiments are necessary (Smith 2004).

In short-term research (2–3 years), Peregrina et al. (2010) found out that the C sequestration rate was influenced by biomass quantity supplied in soil by barley cover crop or resident vegetation, in favor of the last one. In the last decades, cover crops have been used for increasing fertility and carbon in the soil, improving soil structure, and reducing tillage and pollution (Dobrei et al. 2015). According to Delgado et al. (2007), cover crops bring many benefits of C sequestration in vineyards, such as increasing soil fertility and a better disease and pest control. Goward (2012), in a comprehensive study, sustain this statement that "cover crops increase the carbon soil stock in vineyards and in the same time lessens the carbon emissions."

High-carbon plants (like cereals and grasses) and micro-macro organism after their incorporation into the soil followed by decomposition released the carbon which remains "sequestered" in the ecosystem (Irving 2015). If the organic matter builds up in the soil faster than its decomposing, the CO_2 released in the atmosphere will decrease (Ohmart 2011). According to Lal (2004), agriculture has the potential to store in the soil up to 60–70% of the total amount of C resulted from natural systems and crop management.

Perennial cover crops from vineyard alleys can increase soil carbon in 5 years, near 1.4 times compared to bare soil (Steenwerth and Belina 2008). Unlike annual crops, perennial crops with deeper and greater root production have the potential to increase C stored into the soil, and yield loss under no-tillage is smaller (Goward 2012). Studding the organic matter from soil in Tasmania, Cotching (2009) found out that inter-row perennial pastures, mulches, and crop residues have a positive influence on soil carbon stock. Legume cover crops bring nitrogen into the soil and to some extent decrease chemical fertilizers and losses of N_2O because of reduction of leaching through the soil (Carlisle et al. 2009). The negative influence of legume cover crops in vineyards may be associated with competition for nutrients with the vines, and on slopes where soil organic matter can be decreased through erosion. The cropping negative influence on C sequestration is sustained by Chan et al. (2011). In mixed cropping-pasture growing, the advantage is that roots/shoot ratio is higher for pastures which return into the soil more carbon than crops (Sanderman and Baldock 2010). Following a model study made by Kroodsma and Field (2006), the C content that might be sequestered by annual crops was converted to vineyards, and result an average of 68 g C m^2 $year^{-1}$. Many studies reveal that cover crops in vineyard middle rows increase soil organic carbon (Celette et al. 2009). In an experiment carried out with the Tempranillo variety for North-Eastern vineyards in Spain, Peregrina et al. (2014) used three cultivation systems: conventional tillage, cover crop—barley, and cover crop—Persian clover for carbon biomass monitoring. After three experimental years, results showed that in cover crops soil organic carbon increase, and the rate of C sequestrated was 0.47 t C ha^{-1} $year^{-1}$ for barley and 1.19 t C ha^{-1} $year^{-1}$ for Persian clover. In an experiment with annual crops, after 5 years of research, results obtained by Steenwerth and Belina (2008) show that two cover crops (Trios = Triticale × trioscale and *Secale cereale*) from a Chardonnay vineyard cumulate 9.45 ± 0.034 and 10.98 ± 0.030 mg C kg^{-1} soil respectively (relative to bare soil 7.18 ± 0.18 mg C kg^{-1}) in the 0–20 cm depth soil.

In vineyards, cover crops combined with conventional tillage undervine reduce the use of chemical fertilizers and increase the soil quality and carbon stocks (Baumgartner et al. 2008; Sainju et al. 2007). Even if not the best way to supply nitrogen to vines, cover crops contribute to the better retaining of nitrogen in soil and decrease the rate of leaching middle rows. Cover crops remove the tractor operations and fuel consumption, increase the soil carbon store, and slow the organic matter decomposition (Carlisle et al. 2009). Cover crops influence N_2O emissions depending on plants species, soil moisture, and texture, time of incorporation, tillage, and carbon availability (Novara et al. 2011). Legume cover crops reduce the amount of nitrogen fertilizers due to the N fixed in nodules from their roots, but at the same time, the high level of nitrogen added by legumes can increase N_2O emissions (Basche et al. 2014). On the other hand, middle-row perennial grasses (millet, ryegrass, wild rice, etc.) use the available nitrogen from the soil and can limit nitrate leaching and N_2O emissions (Feyereisen et al. 2006).

Undoubtedly, cover crops in vineyards increase soil carbon storage and nitrogen levels with the advantage that they can lower needs for synthetic fertilizers, reduce nitrogen leaching through the soil, and decrease losses of N_2O.

Besides cover crops, in organic viticulture, weeds and pests can be controlled by creating a habitat for beneficial insects, maintaining vine balance and integrated canopy management (Basche et al. 2014), insectary plantings to control pests, growing Phylloxera-resistant varieties (cultivars), or by using macerate from herbs or plants for spraying (e.g., nettle (*Urtica* ssp.) play an important role in organic viticulture, being used as an insecticide, fungicide, fertilizer, and accelerator in the composting process. The nettle is rich in nitrogen, potassium, calcium, and iron, and phosphorus in microorganisms, trace elements, and vitamin complex (A, B_2, C, and K) stimulate plant growth and increase resistance to diseases like gray mold of grapes and rust, including lice and spiders (European Commision & EFSA 2016).

6 Conclusions

There are few data concerning the GHG emission and C sequestration in vineyards, but the general opinion is that the quantity produced is smaller relative to other crops, and at the same time, vine "consumes" CO_2 by photosynthesis. Even if it is produced in smaller quantities than CO_2, the most harmful greenhouse gas in the vineyard is N_2O. To reduce N_2O emissions in vineyards, application of N fertilizers must be used in the right rate of product, in the right place, and at the right time. Among other management methods, cover crops are useful in declining N_2O emissions and increasing C sequestration. Irrespective of the method, SOC changes react slowly, and for noticeable changes, long-term experiments are required. For GHG mitigation in vineyards, alternatives are conservation tillage and no-till systems when more/most carbon enters into the soil organic matter and less CO_2 is produced.

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