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Greenhouse gas emissions from viticulture: a PRISMA systematic review[1]

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ABSTRACT

Grapes are considered one of the world leading fruit crops. They can be grown in various climatic conditions and are highly economically important. Excessive management practices, such as soil preparation, abuse of nitrogen fertilizers and tractors traffic in the vineyard, may reduce the soil fertility and biodiversity, besides altering the balance of ecosystems and the fluxes of greenhouse gases emitted by the soil. This article aimed to develop a systematic review of greenhouse gas emissions from viticulture, in order to present a global perspective on the subject. The Preferred Reporting Items for Systematic Reviews (PRISMA) methodology was used, as well as the terms (“grape growing” OR “viticulture” OR “vineyard” OR “grape cultivation”) AND (“nitrous oxide” OR “carbon dioxide” OR “methane” OR “greenhouse gas”), which should appear in the article title, abstract or keywords. The analysis included 29 articles from the Scopus and Web of Science databases. The results mainly showed the relationship between nitrogen and organic fertilizers and soil texture, in addition to the relation between soil preparation practices and soil carbon emissions, and the influence of the soil water content on greenhouse gas emissions. The association of local climate conditions, management practices and soil characteristics can explain the significant variability of the observed results. Understanding the spatiotemporal emission dynamics and the determining factors allows the development of measures for effective greenhouse gas emissions mitigation, thus reducing the impact of global warming.

KEYWORDS: Grape, nitrogen fertilizers, soil management.

RESUMO

Emissões de gases de efeito estufa pela viticultura: uma revisão sistemática PRISMA

A uva é considerada umas das principais culturas frutíferas no mundo, podendo ser cultivada nas mais diferentes condições climáticas e possuindo grande importância econômica. O excesso de práticas de manejo, como o preparo do solo, abuso de fertilizantes nitrogenados e tráfego de tratores na vinha, pode reduzir a fertilidade e a biodiversidade do solo, além de alterar o equilíbrio dos ecossistemas e dos fluxos dos gases de efeito estufa emitidos pelo solo. Objetivou-se desenvolver uma revisão sistemática a respeito das emissões de gases de efeito estufa pela viticultura, com o intuito de apresentar uma perspectiva global sobre o assunto. Foi utilizada a metodologia Preferred Reporting Items for Systematic Reviews (PRISMA), bem como os termos (“grape growing” OR “viticulture” OR “vineyard” OR “grape cultivation”) AND (“nitrous oxide” OR “carbon dioxide” OR “methane” OR “grenhouse gas”), os quais deveriam aparecer no título do artigo ou no resumo ou nas palavras-chave. A análise incluiu 29 artigos das bases de dados Scopus e Web of Science. Os resultados mostram, principalmente, a relação entre fertilizantes nitrogenados e orgânicos e a textura do solo, além da relação das práticas de preparo do solo e emissões do carbono do solo, e a influência do conteúdo de água no solo sobre as emissões de gases de efeito estufa. A associação das condições climáticas locais, práticas de manejo e características do solo pode explicar a grande variabilidade dos resultados observados. A compreensão da dinâmica de emissão espaço-temporal e dos fatores determinantes permitem desenvolver medidas para uma mitigação eficaz das emissões de gases de efeito estufa, possibilitando reduzir o impacto do aquecimento global.

PALAVRAS-CHAVE: Uva, fertilizantes nitrogenados, manejo do solo.

INTRODUCTION

Grapes are one of the leading fruit crops in the world. In 2022, viticulture occupied an area of 7,254,512 hectares worldwide, 6.6 % less than in 2004. In contrast, its production increased by 17.45 % during the same period (IOV 2023). This production increase, even facing cultivated land reduction, highlights how much management practices influence yield (Gattullo et al. 2020). In 2022, the leading grape-producing countries were China, Italy, France, United States and Spain, accounting together for 51.7 %

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of the world production, while Brazil occupied the fourteenth place, accounting for 1.9 % (IOV 2023).

Intensified soil management and preparation, associated with excessive nitrogen fertilizers, reduce the soil fertility and biodiversity and alter the balance of ecosystems and the greenhouse gases emitted by the soil fluxes (Gattullo et al. 2020). The excessive use of agrochemicals and the traffic of agricultural machinery, especially tractors, increase the soil compaction, reducing the O_2 availability and promoting a CO_2 emission decrease and a N_2O and CH_4 increase (Brentrup et al. 2000). It can also increase soil runoff, causing erosion and, consequentely, reducing the topsoil and soil organic matter, thus decreasing the soil C retention capacity and promoting a CO_2 increase (Bogunovic et al. 2019).

Agricultural soils are major sources of greenhouse gas in the atmosphere. Nitrogen fertilizers stimulate the nitrification and denitrification processes in the soil, being the main processes producing nitrous oxide (N_2O) (Signor & Cerri 2013). On the other hand, the soil disturbance and cultivation of cover crops, as well as soil moisture, strongly influence the processes of carbon (C) fixation and regeneration responsible for regulating the fluxes of carbon dioxide (CO_2) and methane (CH_4) from the soil to the atmosphere (Gattullo et al. 2020).

The year 2019 was a record year for atmospheric concentrations of CO_2 for the last 2 million years, and CH_4 and N_2O for the last 800,000 years (IPCC 2023). The agricultural sector was responsible for 22 % of the global net emissions (59 ± 6.6 Gt CO_2-eq) (IPCC 2023). However, agricultural soils can contribute significantly to mitigating emissions, acting either as sinks or sources of these gases, depending on their management (Zaman et al. 2021).

The proper soil management promotes a sustainable agriculture, being part of the Sustainable Development Goals (SDG) that make up the 2030 agenda, which aims to sustainably increase yield and food production through agricultural practices that progressively improve the soil quality and increase environmental resilience (ONU 2015). Thus, this study is related to the Target 13.3 ("Improving education, raising awareness and human and institutional capacity on mitigation, adaptation, impact reduction and early warning of climate change") and the Target 2.4 ("By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, help maintain ecosystems, strengthen adaptive capacity to climate change, extreme weather, droughts, floods and other disasters, and progressively improve land and soil quality") of the SDG (ONU 2015).

Given the relevance of the topic addressed, the study performs a PRISMA review to assess greenhouse gas emissions from viticulture, establishing the following questions: what factors are investigated in determining greenhouse gas emissions from viticulture, and how do they influence greenhouse gas emissions in viticulture?

MATERIAL AND METHODS

The Preferred Reporting Items for Systematic Reviews (PRISMA) methodology was used. It extensively examines all published articles on the studied subject to find answers to a clearly defined question. It is necessary to use several inclusion and exclusion criteria to achieve this objective, choosing the best articles for reviewing and summarizing their results (Selçuk 2019).

The Scopus and Web of Science (WoS) electronic databases were searched for peer-reviewed articles published up to June 2024, written in English or Spanish. The search terms were combined with Boolean operators to find the most eligible studies, and the terms used in the search were ("grape growing" OR "viticulture" OR "vineyard" OR "grape cultivation") AND ("nitrous oxide" OR "carbon dioxide" OR "methane" OR "greenhouse gas"). These terms should appear in the article title, abstract or keywords.

Three phases selected the final articles: the first screened the title and abstract; the second screened articles by reading the abstracts; and the third included reading the selected articles and tabulating the results.

Articles were eligible if they measured greenhouse gas emissions (CO_2, N_2O or CH_4) in vineyard soils and presented these results clearly, or could be determined from the data presented. This measurement could be done *in situ* or through estimates. The research excluded articles that were not available in full, those that presented the data only in graphs (since the removal of such data gives rise to error), those that evaluated how the increase in atmospheric CO_2 concentration would affect the vine photosynthetic process, respiration, growth and yield, and those that assessed the carbon footprint and presented the results of emissions in liters.

A reviewer searched for the aforementioned terms to identify relevant studies, and two reviewers independently assessed the title, abstract and keywords for all articles returned. The criteria previously mentioned determined eligibility for inclusion in the study. In case of disagreement between the reviewers, they tried to reach a consensus. The potentially relevant articles were read in full, applying the inclusion and exclusion criteria again to select the studies to include in the review.

The extracted data were recorded in an electronic spreadsheet, considering the objectives of the systematic review to ensure that all relevant data were identified, namely: identification of the article, meteorological characterization of the studied site, characterization of the evaluated soil, characterization of the vineyard, management of the applied soil (type, volume and months in which irrigation occurred, type and quantity of fertilizers used, cover vegetation and its maintenance), the form of measuring gases, evaluation period and the observed results [CO_2, N_2O and CH_4 emissions, influence of the management on emissions, ammonia (NH_3) and nitrate (NH_4)].

The search identified 201 articles in Scopus and 7 in the Web of Science. After removing duplicate articles, 203 studies remained. The title reading stage eliminated 115 articles, leaving 88. Next, the abstract reading excluded 25 works, keeping 63 potentially relevant articles for a full reading. The eligibility criteria selected 36 relevant articles. Finally, after full reading and applying the inclusion and exclusion criteria, 29 articles remained for the development of this systematic review (Figure 1).

RESULTS AND DISCUSSION

The search for studies on greenhouse gas emissions from viticulture in the Scopus and WoS databases showed that the selected articles began to be published in 2004, totaling 29 articles until June 2024. The years of 2018 and 2022 displayed the most significant number of studies, with 5 and 4

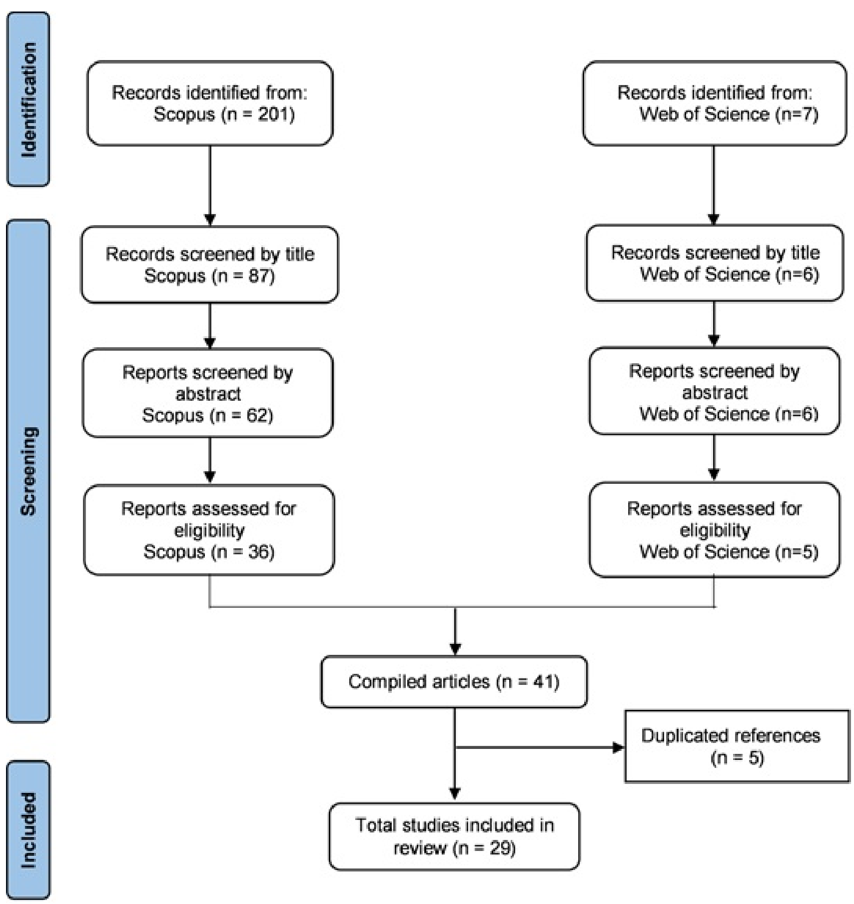

Figure 1. Flowchart presenting the items for producing the systematic review. Source: adapted from Page et al. (2021).

publications per year, respectively (Figure 2). Of the evaluated studies, 13 were carried out before 2015, while the remaining 16 were carried out after 2015.

The 2030 global agenda justifies the increase in publications after 2015. The Agenda, carried out by the United Nations in 2015, promoted sustainable agriculture as one of the Sustainable Development Goals (SDG). The aim is to sustainably increase yield and food production through resilient agricultural practices that progressively improve soil quality to strengthen the capacity to adapt to climate change (ONU 2015).

Although this subject is gaining more and more notoriety, it is possible to observe that there are still few studies on the topic associated with vinery production, pointing out the need for more research to understand better the behavior of greenhouse gas emissions from soils cultivated with vines, since climate change caused by the increase in greenhouse gas emissions has a significant impact on agriculture and, consequently, on the world economy (IPCC 2023).

The journal that contributed most to greenhouse gas research in vineyard soils was *Agriculture, Ecosystems and Environment*, with 20.69 % of the published studies. The following most relevant journals were *Agricultural Water Management*, *Journal of Cleaner Production*, *Applied Soil Ecology* and *Soil Science Society of America Journal*. Each one of these journals accounted for 6.90 % of the studies on the subject. The remaining journals (51.71 %) published only one article on the subject.

Regarding geographic distribution, a high variability of the studied regions was observed, with a predominance of the United States (36.67 %) and Italy (16.67 %). China, Croatia and Hungary performed two studies for each country (6.67 %).

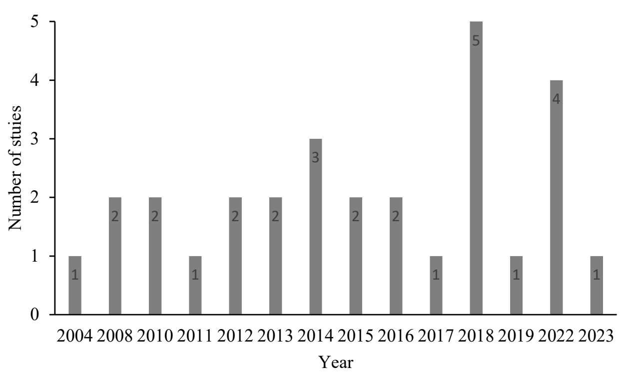

Figure 2. Temporal distribution of the selected studies.

The other evaluated countries were Argentina, Australia, Canada, Cyprus, Greece, Portugal, Spain and Turkey, with one publication each (3.33 %). Of the largest world grape producers in 2022 (China, Italy, France, United States and Spain), only France was not represented in the literature on greenhouse gas emissions (IOV 2023).

The researchers grouped the articles according to thematic areas (Table 1). Most studies assessed the relationship between fertilization management (24.14 %) and greenhouse gas emissions due to the great influence of nitrogen on the greenhouse gas emissions. The second most evaluated theme was soil management (18.96 %), followed by cover crops (17.24 %). In smaller numbers, studies were observed on area monitoring (6.90 %), irrigation depth (6.90 %), phenological stages (6.90 %), carbon footprint (5.17 %), machinery traffic (5.17 %), position concerning the crop line (line and between lines) (3.45 %), biochar application (3.45 %) and irrigation method (1.72 %).

The studies grouped under the heading of fertilizer management evaluated organic and mineral fertilization compared to unfertilized soil and compared among different nitrogen sources. Table 2 shows the nitrogen sources, fertilizer emission factor, studied soil clay content and local climatic characteristics of some studies that evaluated N_2O emissions from fertilizer application. Other factors contributing to emissions are soil preparation, soil temperature, soil water content and season.

The emission factor (EF) refers to the average emission rate of nitrous oxide for a given nitrogen source (IPCC 2019). This value was calculated in those studies that did not present the emission factor but contained the data necessary for its determination. This factor determination is based on refining the IPCC report data (IPCC 2019): $EF = [(N_2O_f - N_2O_c)/N_f] \times 100$, where: EF is the emission factor (%); N_2O_f the N_2O emission during the experimental period in a fertilized plot (kg ha^{-1}); N_2O_c the N_2O emission during the experimental period in a control plot (kg ha^{-1}); and N_f the nitrogen input (kg ha^{-1}).

In the evaluated studies, organic fertilizers presented an emission factor between 0.02 and 13.4 %, while mineral fertilizers ranged from 0.16 to 15.1 %. Mineral nitrogen fertilizers promoted higher N_2O emissions than organic fertilizers. Verhoeven & Six (2014) observed the highest emissions. The authors concluded that up to 15.1 %

Table 1. Distribution of selected articles by thematic area.

Thematic area	Nº of articles	Authors
Fertilization management	14	Garland et al. 2011; Peregrina et al. 2012; Tatti et al. 2012; Garland et al. 2014; Cheng et al. 2015; Brunori et al. 2016; Fentabil et al. 2016; Horel et al. 2018; Guo et al. 2022; Minardi et al. 2022; Litskas et al. 2013; Marques et al. 2018; Deng et al. 2022; Wong et al. 2023
Soil management	11	Steenwerth & Belina 2008a and 2008b; Steenwerth et al. 2010; Steenwerth & Belina 2010; Garland et al. 2011; Garland et al. 2014; Wolff et al. 2018; Deng et al. 2018*; Horel et al. 2018; Marques et al. 2018; Bogunovic et al. 2019
Cover crop	10	Steenwerth & Belina 2008a and 2008b; Steenwerth et al. 2010; Garland et al. 2014; Uliarte et al. 2014; Fentabil et al. 2016**; Wolff et al. 2018; Marques et al. 2018; Bogunovic et al. 2019; Deng et al. 2018
Irrigation depth	4	Steenwerth & Belina 2010; Verhoeven & Six 2014; Marras et al. 2015; Guo et al. 2022
Phenological stages	4	Garland et al. 2014; Horel et al. 2018; Spano et al. 2004; Marras et al. 2015
Area monitoring	4	Spano et al. 2004; Livesley et al. 2013; Kara et al. 2022; Deng et al. 2022
Carbon footprint	3	Litskas et al. 2013; Marras et al. 2015; Michos et al. 2018
Machinery traffic	3	Bogunovic et al. 2017; Bogunovic et al. 2019; Minardi et al. 2022
Biochar	2	Verhoeven & Six 2014; Horel et al. 2018
Functional locations	2	Garland et al. 2014; Verhoeven & Six 2014
Irrigation method	1	Fentabil et al. 2016

* The study performed mathematical modeling to predict greenhouse gas emissions due to different management practices; ** the study compared applying mulch, composed of crushed tree bark and wood chips, to the bare soil.

Table 2. N_2O emission factors for organic and mineral fertilizers evaluated by the selected articles.

Fertilizer	Author	N_2O emission factor (%)*	Average rainfall (mm)	Average temperature (ºC)	Soil's clay content (%)
	Compound				
Made from shredded bark and wood shavings	Fentabil et al. 2016	2.65	346	9.6	-
Compound** (immediately incorporated)	Minardi et al. 2022	0.09-0.37	800-1,100	13	42
Compound** (without incorporation)	Minardi et al. 2022	0.02-0.31	800-1,100	13	44.6
	Manure				
Chicken manure 1	Cheng et al. 2015	1.95	1,177	15.7	17
Chicken manure 2	Cheng et al. 2015	0.20	1,177	15.7	17
	Bran				
Rapeseed meal	Cheng et al. 2015	1.49	1,177	15.7	17
	Cover crop				
Legumes	Garland et al. 2011	0.13	42.7	20.9	-
Dwarf barley	Wolff et al. 2018	0.12	-	-	25
Barley	Wolff et al. 2018	0.12-0.30	-	-	25
	Biochar				
Walnut shell	Verhoeven & Six 2014	1.7-11.7	297	13.8	23
Pine chip	Verhoeven & Six 2014	2.4-13.4	297	13.8	23
	Mineral fertilizer				
Ammonium nitrate - urea***	Garland et al. 2011	1.4	42.7	20.9	-
Ammonium nitrate - urea*** (single application)	Garland et al. 2014	7.5	42.7	20.9	19
Ammonium nitrate - urea*** (three applications)	Garland et al. 2014	10.4	42.7	20.9	19
Ammonium nitrate	Tatti et al. 2012	0.16	40.5	14.1	33.2
Ammonium sulphate (with incorporation of cover crop)	Marques et al. 2018	0.41-1.71	1,170	14.1	30
Ammonium sulphate (without incorporation of cover crop)	Marques et al. 2018	0.17-1.23	1,170	14.1	30
Urea	Guo et al. 2022	0.58-0.67	638	11.0	0.56
Urea	Fentabil et al. 2016	3.02	346	9.6	-
Not informed	Verhoeven & Six 2014	1.4-15.1	297	13.8	23

* Some authors did not present the emission factors nor sufficient data to calculate them, so the table above does not display their data; ** the compound was obtained commercially, and the author does not specify which inputs were part of its composition; *** liquid fertilizer containing a mixture of urea and ammonium nitrate (32 % of N).

of the applied synthetic nitrogen can be converted to N_2O, while different biochar emissions reached up to 13.4 %. The observed values were much higher than those presented by the IPCC (2019), whith an average of 0.010 (95 % CI 0.002-0.018) for synthetic and organic fertilizers. According to the IPCC (2019), the climate region (humid or dry), type of fertilizer, application rate, water management, soil cover, soil texture class, soil C content and soil alkalinity are the main factors influencing the N_2O emission factor.

Most of the selected studies (55.17 %) reported using some form of irrigation. Among those that did it, 64.7 % used drip irrigation, 5.89 % sprinklers, 5.89 % flood irrigation and 11.76 % did not report the form of irrigation used. Meanwhile, 20.69 % of the studies did not use irrigation, 24.14 % of the selected articles did not report whether or not they used irrigation, and 11.76 % were incubation experiments and worked with 60 and 70 % of field capacity. Table 3 shows the accumulated emissions of N_2O, CO_2 and CH_4 described in the selected studies due to the use or not of some form of irrigation.

It is possible to observe that areas that received some form of irrigation presented higher N_2O and CO_2 accumulated emissions and lower CH_4 emissions than areas without irrigation. The increase in soil water content increases the denitrification process and, as incomplete, denitrification produces and emits N_2O and NO (Brentrup et al. 2000). The increase in soil moisture also increases CO_2 emissions, since it stimulates the microbial activity. However, waterlogged soils favor CH_4 emissions (Cardoso & Andreote 2016).

Few among the selected studies analyze the CH_4 emissions: only Litskas et al. (2013) quantified their emissions in a non-irrigated area. At the same time, Wolff et al. (2018) evaluated an irrigated area. Although increased soil water content increases CH_4 emissions (Le Mer & Roger 2001), the assessed studies did not show this behavior. In these studies, the accumulated CH_4 emission was higher in the non-irrigated area. Other factors, such as soil texture and aeration, may be responsible for these results, but the authors did not present these data (Serrano-Silva et al. 2014, Le Mer & Roger 2001). The irrigated area evaluated by Wolff et al. (2018) had an average soil texture of 42 % of silt, 33 % of sand and 25 % of clay. Sandier soils present lower CH_4 emissions, when compared to clayey soils, and may behave as gas sinks (Cardoso & Andreote 2016).

N_2O was the greenhouse gas most studied by the selected authors (47.5 %). This selection can be explained mainly by the amount of nitrogen fertilizers applied to this crop and their relationship with irrigation events, rainfall, temperature and soil texture, increasing N_2O emissions (Hassan et al. 2022). The CO_2 emissions from the soil (45 %) were also extensively studied, since soil preparation practices are directly related to the increase in soil carbon release (Silva et al. 2022).

The least studied greenhouse gas was CH_4 (7.5 %), which requires anaerobic conditions for its production. Applying nitrogen fertilizers reduces the CH_4 production, since these compounds compete for the same enzyme, nitrogen reductase, involved in producing N_2O (Serrano-Silva et al. 2014). In addition, many crops are grown under irrigated conditions, affecting the soil CH_4 production. Therefore, including this gas in the evaluations would be essential to bring a greater robustness to the study.

Most studies used the chamber method to determine greenhouse gas emissions (58.62 %). The chamber method studies varied among static, dynamic, ventilated, closed, open and automatic types, coupled with non-dispersive infrared gas analyzer and data logger systems. The other measurement methodologies consisted of estimates (17.24 %), incubation (10.34 %), Eddy covariance technique (6.90 %), net ecosystem production (NEP) (3.45 %) and non-steady state (3.45 %).

The studied organic fertilizers presented different results regarding their influence on greenhouse gas emissions. Tatti et al. (2012) and

Table 3. Cumulative greenhouse gas emissions from studies that did or did not use some form of irrigation.

Cumulative greenhouse gas emissions	Irrigated		Without irrigation	
	Minimum	Maximum	Minimum	Maximum
N_2O (kg of N_2O-N ha^{-1} $year^{-1}$)*	0.13	4.14	0.003	1.38
CH_4 (kg of CH_4-C ha^{-1} $year^{-1}$)*	-0.54	0.55	0.012	1.18
CO_2 (kg of CO_2-C ha^{-1} $year^{-1}$)*	-7,150.5	38.84×10^9	624	3,677

* The cumulative emissions presented by the authors were all converted to the same measurement unit. The study did not consider data presented as flows and those that could be transformed into cumulative emissions.

Peregrina et al. (2012) examined the impact of composts on soil CO_2 emissions, compared to soils without fertilization. Peregrina et al. (2012) evaluated two doses of composts (8 and 25 t ha^{-1}) produced from fresh mushrooms without any processing and from mushrooms composted under anaerobic conditions in a soil classified as fine-loamy, mixed, thermic Typic Haploxerepts (USDA 1999).

The substrate was applied manually in May 2006, April 2007, February 2008 and March 2009, and the researchers plowed the soil immediately after. The application of low doses did not promote changes in emissions, while the high dose doubled, only once, soil CO_2 emissions. Wong et al. (2023) evaluated a sandy loam soil with four doses (0, 4.5, 9.0 and 13.5 Mg ha^{-1}) of cattle manure with green pasture remains and observed that, despite seasonal fluctuations in CO_2 emissions, accumulated emissions were not different between treatments.

Tatti et al. (2012) performed incubation using a Calcaric Cambisol (FAO 2015) managed in two ways: the first with 15 t ha^{-1} of compost produced from urban organic waste and the second with 50 kg of N ha^{-1} of mineral fertilizer. The authors applied 40 g of compost as a corrective to the studied soils, compared them to soils without corrections and observed that adding the compost increased CO_2 emissions (between: 1.0 and 1.5 mg of CO_2-C kg^{-1} of dry soil h^{-1}; data estimated by the authors), when compared to the treatment without correction (varying between 0.14 and 0.44 mg of CO_2-C kg^{-1} of dry soil h^{-1}). On the other hand, Horel et al. (2018), when applying 14.7 t ha^{-1} of manure in a Cambisol (FAO 2015), reached opposite results, with emissions from organic fertilization lower than CO_2 emissions from unfertilized soil.

Regarding N_2O emissions, Minardi et al. (2022) observed that applying 9 t ha^{-1} of a commercially obtained compound increased N_2O emissions from an Endogleyic Calcisol (FAO 2015), when compared to an unfertilized soil. The organic fertilizer evaluated by Minard et al. (2022) was characterized before its use; however, the article did not report the raw material from which it was derived. Horel et al. (2018) also observed an increase in N_2O emissions by applying 14.7 t ha^{-1} of manure, when compared to unfertilized soil. Tatti et al. (2012) observed that using organic fertilizer reduced N_2O emissions, in relation to unfertilized soil.

When evaluating greenhouse gas emissions from soil with mineral fertilizer application, if compared to soil without correction, Tatti et al. (2012) used a Calcaric Cambisol (FAO 2015) managed with 50 kg of N ha^{-1} of ammonium nitrate in an incubation. The soils were further corrected with an ammonium nitrate solution at a dose of 87 mg of N kg^{-1} of dry soil and compared to the soil without correction. The authors observed increased N_2O emissions in soils fertilized with mineral fertilizer (0.51 µg of N_2O-N kg^{-1} h^{-1}), when compared to soil without correction (0.035 µg of N_2O-N kg^{-1} h^{-1}). In contrast, CO_2 emissions were indifferent to the addition of ammonium nitrate. The CO_2 and N_2O emissions assessed by Marques et al. (2018), when applying 50 kg of N ha^{-1} of ammonium sulfate, were not statistically different from the treatment without fertilizer in a soil classified as Dystric Cambisol (FAO 2015).

Other studies have compared how different nitrogen sources or varying doses of the same fertilizer influenced greenhouse gas emissions. Fentabil et al. (2016) compared N_2O emissions from the application of 40 kg of N ha^{-1} in the form of compost (produced from grape pomace, straw, crushed bark and cow manure), compared to the same dose applied in the form of urea, and observed no statistical difference between the two forms of fertilizer in the soil with a predominantly sandy texture, but with a significant amount of organic matter, clay and silt (Skaha Sandy Loam; USDA 1999).

Garland et al. (2011) analyzed the use of cover crops as a nitrogen source and observed that adding 47 kg of N ha^{-1} of organic fertilizer as mulch emitted less N_2O than plots fertilized with 5 kg of N ha^{-1} - urea-ammonium nitrate. Incorporating cover crops may have different effects on N_2O emissions, which may have improved nutrient cycling and nitrogen use efficiency, what could justify the N_2O emissions reduction.

Garland et al. (2014), Cheng et al. (2015) and Brunori et al. (2016) found opposite results with emissions from organic fertilization higher than those emitted by mineral fertilizers. Garland et al. (2014) observed increased emissions in areas that used legumes as fertilizer, when compared to urea-ammonium nitrate fertilization. The soil organic matter content may have been high due to the applied plant cover, which acts as an energy and carbon source for microorganisms that consume O_2, providing conditions to increase N_2O emissions during decomposition, mainly as increasing soil moisture, which favors the denitrification process and promotes emissions of this gas (Brentrup et al. 2000). Emissions from individual management practices, such as cover cropping, when associated with other events favorable to N_2O production, such as rainfall, climatic events and weather, can increase N_2O emissions (Garland et al. 2014).

The incubation experiment carried out by Cheng et al. (2015) demonstrated that two types of chicken manure with different C/N ratios and rapeseed meal applied at a dosage of 100 mg of N kg $^{-1}$ of soil promoted higher emissions of N_2O and CO_2 than plots that received mineral fertilizer. Although applying material with a low C/N ratio increased the availability of N for microorganisms and plants, once associated with negative environmental consequences, it can lead to increased emissions.

Brunori et al. (2016) compared the conventional management system, with the application of mineral fertilizer, to an organic management system, with manure application, and observed higher CO_2 emissions in vineyards with organic fertilization. Manure increased the soil organic matter content, increasing the substrate availability for decomposing microorganisms, thus increasing CO_2 emissions.

Guo et al. (2022) evaluated three N doses: 664 (dose traditionally applied), 413, 460 and 460 kg ha^{-1} together with the nitrification inhibitor 3,4-dimethylpyrazole phosphate (DMPP), applied in a split manner, distributed on the following dates: April 30, July 3, July 30 and November 7, and observed that reducing the mineral fertilizer dose decreased the N_2O emissions, if compared to the rate traditionally applied. The association of a reduced dose of urea with the nitrification inhibitor also led to significant reductions in N_2O emissions. The DMPP increased the nitrogen use efficiency, slowing down the oxidation of NO_3-N via nitrification, leading to a reduction in N_2O emissions (Guo et al. 2022).

Litskas et al. (2013) grouped several vineyards with different fertilizer input consumptions and observed that the groups with lower consumptions (32.1 kg ha^{-1} and 68.0 kg ha^{-1} of N) presented lower N_2O, CO_2 and CH_4 emissions than the group with higher fertilizer consumption (179.1 kg ha^{-1} of N). The N_2O simulations by Deng et al. (2022) also showed decreasing trends in emissions due to the reduction of nitrogen inputs.

Most studies observed the influence of management and soil preparation practices on CO_2 and N_2O emissions. Only Wolff et al. (2018) observed CH_4 fluxes. However, conventional soil preparation, minimum cultivation of dwarf barley, and annual incorporation of barley cover crops did not influence soil CH_4 emissions.

Different papers displayed contradictory results when evaluating how management practices influence CO_2 emissions. According to Steenwerth & Belina (2008a), soil preparation does not promote a difference in emissions. Wolff et al. (2018) observed the same result when they evaluated conventional soil preparation, minimum cultivation of dwarf barley, and annual incorporation of barley cover crop. Marques et al. (2018) also noticed the same CO_2 emissions when comparing conventional soil preparation with no-tillage.

When evaluating how the incorporation or cutting of vegetation influenced the accumulated CO_2 emissions over two years, Steenwerth et al. (2010) observed that only in the second year the management highlighted differences regarding the cover crop incorporation. The incorporation of spontaneous vegetation and the barley cover crop presented higher emissions than when the barley was only mowed (10.99 ± 0.30, 10.11 ± 0.49 and 8.57 ± 0.54 Mg of CO_2-C ha^{-1}, respectively).

Horel et al. (2018) also concluded that soil preparation increases global CO_2 emissions. Bogunovi et al. (2019) compared conventional soil preparation, long-term interrow grass cover, soil preparation in a given year followed by a year without soil preparation and allowing spontaneous vegetation to serve as cover, and soil preparation in one year followed by a year with spontaneous vegetation serving as cover and soil preparation the following year. The different evaluated management methods showed higher emissions in the tillage in a given year with spontaneous vegetation serving as cover soil preparation the following year, followed by continuous grass coverage, fallowed tillage in a given year followed by a year without soil preparation and allowing spontaneous vegetation to serve as cover and conventional tillage (120.3, 111.4, 71.7 and 51.5 kg of CO_2 ha^{-1} year^{-1}, respectively). The higher CO_2 emissions from the mulch treatments derived from increased microbiological activity associated with the rise in carbon availability in the soil (Bogunovic et al. 2019).

Regarding the influence of management practices on N_2O emissions, Garland et al. (2011) found no difference when comparing conventional tillage *versus* no-tillage practices. Wolff et al.

(2018) also found no statistical difference among conventional soil preparation, minimum cultivation of dwarf barley and annual incorporation of barley cover crop. At the same time, Steenwerth & Belina (2008b) observed that the soil preparation increased daily N_2O emissions. The mathematical modeling performed by Deng et al. (2018) corroborated this result, with conventional management presenting slightly higher emissions than reduced management and no management. Marques et al. (2018) reached the same conclusions, in areas where soil preparation displayed higher emissions than the no-tillage system.

Only one study (Steenwerth & Belina 2010) evaluated herbicide behavior. The authors compared the use of herbicides for weed control with the use of Clemens® mechanical cultivators and observed that areas using mechanical cultivators presented a slightly higher total carbon and microbial biomass and lower N_2O emissions than the herbicide use.

Individual handling practices may not immediately affect N_2O emissions. However, they may favor emissions when combined with other events such as rainfall, irrigation, soil temperature and soil texture (Garland et al. 2014).

The selected studies evaluated the use of cover crops grown widely, and, like the other factors, its use generated different results. Regarding CO_2 emissions, Wolff et al. (2018) found no statistical difference between soil without cover and soil cultivated using cover crops, dwarf barley and barley. The spontaneous vegetation evaluated by Marques et al. (2018) also did not promote a statistical difference in accumulated emissions, when compared to soil without cover. On the other hand, Steenwerth & Belina (2008a) observed that the cover crops Trios 102 (*Triticale x Triosecale*) and Marced Rey (*Secale cereale*) presented higher emissions than the perennial barley crop.

Winter cover crops studied by Steenwerth et al. (2010) presented lower accumulated CO_2 emissions than spontaneous vegetation, when both were incorporated into the soil. Uliarte et al. (2014) evaluated the summer emissions of native herbaceous vegetation, exotic species, weeds and bare soil, either with or without water restriction. During the summer, without water restriction, they observed that only the bare soil and native winter grass (*Secale cereale* L.) behaved as a CO_2 source. The weed *Cynodon dactylon* presented the highest absorption, which was different from the other species, except for native grass [*Digitaria californica* (Benth.) Henrad], while the lowest rates were observed for exotic grass (*Festuca arundinacea* Schreb.) and native grass [*Nassella tenuis* (Phil.) Barkworth]. As submitted to water restriction conditions, the exotic grass, native grass, native winter grass, exotic legume varieties and bare soil (*F. Arundinacea*, *N. tenuis*, *S. cereale* and *Trifolium repens* L., respectively) behaved as a source of CO_2. Weeds and native C4 species continued acting as drains, but in smaller quantities than without the water restriction condition. Bogunovic et al. (2019) also observed that the use of cover crops increased CO_2 emissions, when compared to conventional management, which consisted of preparing the soil two to three times a year during spontaneous vegetation growth, leaving the soil uncovered.

Regarding the influence of cover crops on N_2O emissions, Garland et al. (2014) compared emissions during the planting year of a legume and the fallow year, describing that the planting year presented emissions seven times higher than the fallow year. When comparing perennial crops to cover crops, Steenwerth & Belina (2008b) observed that the accumulated flux of N_2O was more significant in the cover crops Trios 102 (*Triticale x Triosecale*) and Marced Rey (*S. cereale*) than in the perennial crop barley.

Fentabil et al. (2016) observed reduced CO_2 emissions after applying mulch composed of shredded tree bark and wood chips, in relation to bare soil. Deng et al. (2018) compared emissions among bare soil and covered with leguminous and non-leguminous covers, and observed that the use of cover crops substantially reduces emissions. Marques et al. (2018) observed no difference when evaluating the impact of the use of resident vegetation on N_2O emissions.

Three authors studied the effect of grape developing phenological stages on greenhouse gas emission and observed that the vineyard behaves as a greenhouse gas source or sink depending on the development phase or the management used. Spano et al. (2004) noticed that vineyards can behave as a CO_2 sink during the grape veraison phase. On the other hand, Horel et al. (2018) assessed emissions during all vineyard phenological stages after soil preparation and addition of biochar and organic fertilizer, and observed that the soil preparation reduces CO_2 emissions until the harvest phase. After this period, emissions from soil with the addition of biochar become lower. The organic fertilizer treatments presented similar emissions during the growth phase and after harvest. The soil adde of manure and biochar presented lower CO_2 emissions during the fruiting and veraison periods. Marras et al. (2015) observed that the vineyard behaved as a net carbon sink during the growth phase, with July and August as the months of most significant consumption. The highest CO_2 consumption occurred during the dry season (May to September), when irrigation occurred.

Garland et al. (2014) assessed N_2O emissions in vinery cultivated areas over two years, observing that N_2O emissions were higher in the crop rows during the growth period. On the other hand, the highest emissions occurred between the rows during dormancy, with the first year presenting much higher emissions than the second, in response to the first rainfall event. Horel et al. (2018) only observed a statistical difference during the maturation and post-harvest phases when there was an increase in N_2O emissions in soils with the addition of biochar and plowed soils.

Other factors, such as irrigation management, machinery traffic, irrigation method, carbon footprint and area monitoring, were evaluated to a lesser extent. Fentabil et al. (2016) studied the irrigation method, as the authors compared micro-sprinkling with dripping; however, they observed that the irrigation method did not affect N_2O emissions.

Bogunovic et al. (2017, 2019) and Minardi et al. (2022) evaluated the influence of machinery traffic on CO_2 and N_2O emissions. Bogunovic et al. (2017) assessed CO_2 emissions due to machinery traffic in four types of management and concluded that yearly inversed grass-covered planting and tillage-managed soil presented lower CO_2 fluxes due to increased soil compaction.

Bogunovic et al. (2019) observed that CO_2 emissions were higher after 3 and 11 tractor passes (spring and autumn, respectively) and lower after six tractor passes (summer). This reduction in emissions may be associated with a decrease in soil water content, which, together with increased compaction due to increased passes, may reduce emissions. The same behavior was not observed after 11 tractor passes, probably due to increased soil water content due to autumn rains (Bogunovic et al. 2019). Minardi et al. (2022) monitored the behavior of soil N_2O fluxes in two areas, with and without machinery traffic, and observed that areas without machinery circulation had lower total organic carbon and nitrogen contents and a lower C/N ratio, what could explain the lower N_2O emissions in the area.

Steenwerth & Belina (2010), Verhoeven & Six (2014), Marras et al. (2015) and Guo et al. (2022) studied the influence of irrigation management on greenhouse gas emissions. Steenwerth & Belina (2010), evaluating the use of mechanical cultivators and herbicides for weed control associated with the presence or absence of irrigation, noticed that the presence of irrigation initially increased N_2O emissions from soils in both forms of control, and that, after subsequent irrigations, emissions became insignificant, not differing between treatments. Verhoeven & Six (2014) observed no significant difference when applying two irrigation volumes (1,268 and 2,534 L) in two years. In this case, irrigation was carried out from April to October by dripping in the crop rows. In the meantime, Guo et al. (2022) studied vines that had a 30-40 % reduction in the water volume applied (control volume: 3,640 m^3 ha^{-1}), pointing out a reduction in N_2O emissions.

Water is considered a limiting factor for greenhouse gas emissions. According to Marras et al. (2015), when water is not a limiting factor (due to irrigation practices), carbon sequestration in vineyards can reach relatively high values.

When comparing emissions between crop lines and between rows, both Garland et al. (2014) and Verhoeven & Six (2014) observed that the areas between rows presented higher N_2O emissions, probably due to the increased N availability provided by cover crops.

Three studies evaluated the carbon footprint of vineyards and found that the main contributors to greenhouse gas emissions are fossil fuels, soil management and fertilizer application (Litskas et al. 2013, Marras et al. 2015, Michos et al. 2018). Rethinking management practices and the amount of fuel and nitrogen fertilizer consumed for grape production makes reducing emissions of N_2O, CO_2 and CH_4 possible.

Spano et al. (2004) measured CO_2 emissions from two regions in Italy and observed that, after irrigation, the soil's CO_2 absorption capacity was reduced, thus concluding that the main factors affecting emissions in the studied conditions were rainfall and irrigation.

Livesley et al. (2013) assessed N_2O and CH_4 emissions on three farms during autumn, winter, spring and summer. The vineyard behaved as a weak CH_4 source during spring and summer, and a sink during autumn. All seasons displayed small fluxes of N_2O, with little correlation between environmental variables, which did not lead to significant differences.

On the other hand, simulations of N_2O emissions for the California state carried out by Deng et al. (2022) showed that the crop type, climate, soil properties, nitrogen fertilization, management carried out and cover crops could explain emissions variations.

Only two studies evaluated the effect of biochar on N_2O (Verhoeven & Six 2014, Horel et al. 2018) and CO_2 (Horel et al. 2018) emissions. Verhoeven & Six (2014) evaluated the effect of biochar derived from walnut shells and pine chips on N_2O emissions over two years. The control treatment consisted of a crop row that received fertilization with mineral fertilizer and a row that received organic fertilization in the form of a cover crop composed mainly of legumes (sweet peas, vetch, broad beans and barley). When evaluating the accumulated emissions of biochar, the authors observed that the pine chips treatment had higher emissions than the control treatment in both years, while the walnut shells biochar did not differ from the control.

Horel et al. (2018) studied the use of biochar associated with soil management practices and organic fertilization and observed how these affected N_2O and CO_2 emissions. The biochar used was commercially purchased, had a European Biochar Certificate and derived from grain husks. The authors observed that adding both manure and biochar to the soil can reduce global soil N_2O emissions. These factors did not reduce emissions significantly, as evaluated separately. Jet CO_2 emissions were higher in the biochar treatment, but these emissions decreased when researchers adopted biochar and manure in synergy. The experiment did not highlight strong correlations between soil water content, temperature or N_2O emissions. CO_2 emissions, on the other hand, showed weak to moderately strong connections with environmental factors.

Several factors influence greenhouse gas emissions, such as grape variety, local climate conditions, soil characteristics and soil management practices, which can explain the great variability observed in the results (Marras et al. 2015). Understanding the detailed spatiotemporal emission dynamics and how these factors interact with each other enables the development of effective methods to mitigate greenhouse gas emissions (Deng et al. 2022).

CONCLUSIONS

1. Greenhouse gas emissions in vineyards have been assessed for over two decades, but few studies have been performd until now on the subject. However, the increase in publications on the topic highlights the global concern. The results show that studies were conducted in 12 countries, most in the United States, followed by Italy. The literature review found no studies on this topic performed in Brazil;
2. The studies selected to compose this review mainly evaluated how fertilizer management, soil management and preparation, and cover crops influence greenhouse gas emissions. The studies showed a high variability in greenhouse gas emissions, which can be explained by soil characteristics, climatic conditions, water volume applied, nitrogen dose provided, soil temperature and soil management practices, among other factors.

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REFERENCES

BOGUNOVIC, I.; ANDABAKA, Z.; STUPIC, D.; PEREIRA, P.; GALIC, M.; NOVAK, K.; TELAK, L. J. Continuous grass coverage as a management practice in humid environment vineyards increases compaction and CO_2 emissions but does not modify must quality. *Land Degradation & Development*, v. 30, n. 18, p. 2347-2359, 2019.

BOGUNOVIC, I.; BILANDZIJA, D.; ANDABAKA, Z.; STUPIC, D.; COMINO, J. R.; CACIC, M.; BREZINSCAK, L.; MALETIC, E.; PEREIRA, P. Soil compaction under different management practices in a Croatian vineyard. *Arabian Journal of Geosciences*, v. 10, e340, 2017.

BRENTRUP, F.; KUSTERS, J.; LAMMEL, J.; KUHLMANN, H. Methods to estimate onfield nitrogen emissions from crop production as an input to LCA studies in the agricultural sector. *International Journal of Life Cycle Assessment*, v. 5, n. 6, p. 349-357, 2000.

BRUNORI, E.; FARINA, R.; BIASI, R. Sustainable viticulture: the carbon-sink function of the vineyard agro-ecosystem. *Agriculture, Ecosystems & Environment*, v. 223, n. 1, p. 10-21, 2016.

CARDOSO, E. J. B. N.; ANDREOTE, F. D. *Microbiologia do solo*. 2. ed. Piracicaba: ESALQ, 2016.

CHENG, Y.; ZHANG, J. B.; MÜLLER, C.; WANG, S. Q. ^{15}N tracing study to understand the N supply associated with organic amendments in a vineyard soil. *Biology and Fertility of Soils*, v. 51, n. 8, p. 983-993, 2015.

DENG, J.; GUO, L.; SALAS, W.; INGRAHAM, P.; CHARRIER-KLOBAS, J. G.; FROLKING, S.; LI, C. A decreasing trend of nitrous oxide emissions from California cropland from 2000 to 2015. *Earth's Future*, v. 10, n. 4, e2021EF002526, 2022.

DENG, J.; LI, C.; BURGER, M.; HORWATH, W. R.; SMART, D.; SIX, J.; GUO, L.; SALAS, W.; FROLKING, S. Assessing short-term impacts of management practices on N_2O emissions from diverse Mediterranean agricultural ecosystems using a biogeochemical model. *Journal of Geophysical Research: Biogeosciences*, v. 123, n. 5, p. 1557-1571, 2018.

FENTABIL, M. M.; NICHOL, C. F.; NEILSEN, G. H.; HANNAM, K. D.; NEILSEN, D.; FORGE, T. A.; JONES, M. D. Effect of micro-irrigation type, N-source and mulching on nitrous oxide emissions in a semi-arid climate: an assessment across two years in a Merlot grape vineyard. *Agricultural Water Management*, v. 171, n. 1, p. 49-62, 2016.

FOOD AND AGRICULTURE ORGANIZATION (FAO). *World reference base for soil resources*: international soil classification system for naming soils and creating legends for soil maps. 4. ed. Rome: FAO, 2015.

GARLAND, G. M.; SUDDICK, E.; BURGER, M.; HORWATH, W. R.; SIX, J. Direct N_2O emissions following transition from conventional till to no-till in a cover cropped Mediterranean vineyard (*Vitis vinifera*). *Agriculture, Ecosystems & Environment*, v. 144, n. 1, p. 423-428, 2011.

GARLAND, G. M.; SUDDICK, E.; BURGER, M.; HORWATH, W. R.; SIX, J. Direct N_2O emissions from a Mediterranean vineyard: event-related baseline measurements. *Agriculture, Ecosystems & Environment*, v. 195, n. 1, p. 44-52, 2014.

GATTULLO, C. E.; MEZZAPESA, G. N.; STELLACCI, A. M.; FERRARA, G.; OCCHIOGROSSO, G.; PETRELLI, G.; CASTELLINI, M.; SPAGNUOLO, M. Cover crop for a sustainable viticulture: effects on soil properties and table grape production. *Agronomy*, v. 10, n. 9, e1334, 2020.

GUO, Y.; JI, Y.; ZHANG, J.; LIU, Q.; HAN, J.; ZHANG, L. Effects of water and nitrogen management on N_2O emissions and NH_3 volatilization from a vineyard in north China. *Agricultural Water Management*, v. 266, e107601, 2022.

HASSAN, M. U.; AAMER, M.; MAHMOOD, A.; AWAN, M. I.; BARBANTI, L.; SELEIMAN, M. F.; BAKHSH, G.; ALKHARABSHEH, H. M.; BABUR, E.; SHAO, J.; RASHEED, A. Management strategies to mitigate N_2O emissions in agriculture. *Life*, v. 12, n. 3, e439, 2022.

HOREL, Á.; TÓTH, E.; GELYBÓ, G.; DENCSŐ, M.; POTYÓ, I. Soil CO_2 and N_2O emission drivers in a vineyard (*Vitis vinifera*) under different soil management systems and amendments. *Sustainability*, v. 10, n. 6, e1811, 2018.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). N_2O emissions from managed soils, and CO_2 emissions from lime and urea application. *In*: DARIO GÓMEZ, D.; IRVING, W. (ed.). *Refinement to the 2006 IPCC guidelines for national greenhouse gas inventories*. Geneva: IPCC, 2019. p. 1-48.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). Summary for policymakers. *In*: TEAM, C. W.; LEE, H.; ROMERO, J. (ed.). *Climate Change 2023*: synthesis report: contribution of working groups I, II and III to the sixth assessment report of the Intergovernmental Panel on Climate Change. Geneva: IPCC, 2023. p. 1-34.

INTERNATIONAL ORGANISATION OF VINE AND WINE (IOV). *World statistics*. 2023. Available at: https://www.oiv.int/what-we-do/global-report?oiv. Access in: Mar. 2023.

KARA, F.; BAS, T.; TALU, N. H. T.; ALOLA, A. A. Investigating the carbon emission aspects of agricultural land utilization in Turkey. *Integrated Environmental Assessment and Management*, v. 18, n. 4, p. 988-996, 2022.

LE MER, J.; ROGER, P. Production, oxidation, emission and consumption of methane by soils: a review. *European Journal of Soil Science*, v. 37, n. 2001, p. 25-50, 2001.

LITSKAS, V. D.; KARAOLIS, C. S.; MENEXES, G. C.; MAMOLOS, A. P.; KOUTSOS, T. M.; KALBURTJI, K. L. Variation of energy flow and greenhouse gas emissions in vineyards located in Natura 2000 sites. *Ecological Indicators*, v. 27, n. 1, p. 1-7, 2013.

LIVESLEY, S. J.; IDCZAK, D.; FEST, B. J. Differences in carbon density and soil CH_4/N_2O flux among remnant and agro-ecosystems established since European settlement in the Mornington peninsula, Australia. *Science of the Total Environment*, v. 465, n. 1, p. 17-25, 2013.

MARQUES, F. J.; PEDROSO, V.; TRINDADE, H.; PEREIRA, J. L. Impact of vineyard cover cropping on carbon dioxide and nitrous oxide emissions in Portugal. *Atmospheric Pollution Research*, v. 9, n. 1, p. 105-111, 2018.

MARRAS, S.; MASIA, S.; DUCE, P.; SPANO, D.; SIRCA, C. Carbon footprint assessment on a mature vineyard. *Agricultural and Forest Meteorology*, v. 214, n. 1, p. 350-356, 2015.

MICHOS, M. C.; MENEXES, G. C.; MAMOLOS, A. P.; TSATSARELIS, C. A.; ANAGNOSTOPOULOS, C. D.; TSABOULA, A. D.; KALBURTJI, K. L. Energy flow, carbon and water footprints in vineyards and orchards to determine environmentally favourable sites in accordance with Natura 2000 perspective. *Journal of Cleaner Production*, v. 187, n.1 , p. 400-408, 2018.

MINARDI, I.; TEZZA, L.; PITACCO, A.; VALENTI, L.; COPPO, L.; GHIGLIENO, I. Evaluation of nitrous oxide emissions from vineyard soil: effect of organic fertilisation and tillage. *Journal of Cleaner Production*, v. 380, e134557, 2022.

ORGANIZAÇÃO DAS NAÇÕES UNIDAS (ONU). *Transformando nosso mundo*: a Agenda 2030 para o Desenvolvimento Sustentável. 2015. Available at: https://brasil.un.org/pt-br/91863-agenda-2030-para-o-desenvolvimento-sustent%C3%A1vel. Access in: Mar. 2023.

PAGE, M. J.; MCKENZIE, J. E.; BOSSUYT, P. M.; BOUTRON, I.; HOFFMANN, T. C.; MULROW, C. D.; SHAMSEER, L.; TETZLAFF, J. M.; AKL, E. A.; BRENNAN, S. E.; CHOU, R. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *British Medical Journal*, v. 71, e372, 2021.

PEREGRINA, F.; LARRIETA, C.; COLINA, M.; MARISCAL-SANCHO, I.; MARTÍN, I.; MARTÍNEZ-VIDAURRE, J. M.; GARCÍA-ESCUDERO, E. Spent mushroom substrates influence soil quality and nitrogen availability in a semiarid vineyard soil. *Soil Science Society of America Journal*, v. 76, n. 5, p. 1655-1666, 2012.

SELÇUK, A. A. A guide for systematic reviews: PRISMA. *Turkish Archives of Otorhinolaryngology*, v. 57, n. 1, e57, 2019.

SERRANO-SILVA, N.; SARRIA-GUZMÁN, Y.; DENDOOVEN, L.; LUNA-GUIDO, M. Methanogenesis and methanotrophy in soil: a review. *Pedosphere*, v. 24, n. 3, p. 291-307, 2014.

SIGNOR, D.; CERRI, C. E. P. Nitrous oxide emissions in agricultural soils: a review. *Pesquisa Agropecuária Tropical*, v. 43, n. 3, p. 322-338, 2013.

SILVA, W. M. D.; BIANCHINI, A.; AMORIM, R. S.; COUTO, E. G.; WEBER, O. L. D. S.; HOSHIDE, A. K.; PEREIRA, P. S.; CREMON, C.; ABREU, D. C. D. Soil efflux of carbon dioxide in Brazilian Cerrado wheat (*Triticum aestivum* L.) under variable soil preparation and irrigation. *Agriculture*, v. 12, n. 2, e163, 2022.

SPANO, D.; DUCE, P.; SNYDER, R. L. Estimate of mass and energy fluxes over grapevine using Eddy covariance technique. *Acta Horticulturae*, v. 664, n. 1, p. 631-368, 2004.

STEENWERTH, K. L.; BELINA, K. M. Vineyard weed management practices influence nitrate leaching and nitrous oxide emissions. *Agriculture, Ecosystems & Environment*, v. 138, n. 1-2, p. 127-131, 2010.

STEENWERTH, K. L.; PIERCE, D. L.; CARLISLE, E. A.; SPENCER, R. G.; SMART, D. R. A vineyard agroecosystem: disturbance and precipitation affect soil respiration under Mediterranean conditions. *Soil Science Society of America Journal*, v. 74, n. 1, p. 231-239, 2010.

STEENWERTH, K.; BELINA, K. M. Cover crops and cultivation: impacts on soil N dynamics and microbiological function in a Mediterranean vineyard agroecosystem. *Applied Soil Ecology*, v. 40, n. 2, p. 370-380, 2008a.

STEENWERTH, K.; BELINA, K. M. Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem. *Applied Soil Ecology*, v. 40, n. 2, p. 359-369, 2008b.

TATTI, E.; GOYER, C.; ZEBARTH, B. J.; BURTON, D. L.; GIOVANNETTI, L.; VITI, C. Short-term effects of mineral and organic fertilizer on denitrifiers, nitrous oxide emissions and denitrification in long-term amended vineyard soils. *Soil Science Society of America Journal*, v. 77, n. 1, p. 113-122, 2012.

ULIARTE, E. M.; PARERA, C. A.; ALESSANDRIA, E. E.; DALMASSO, A. D. Intercambio gaseoso y eficiencia en el uso del agua de cultivos de cobertura con especies nativas (Mendoza, Argentina), exóticas cultivadas y malezas. *Agriscientia*, v. 31, n. 2, p. 49-61, 2014.

UNITED STATES DEPARTMENT OF AGRICULTURE (USDA). Soil Survey Staff. *Soil taxonomy*: a basic system of soil classification for making and interpreting soil surveys. 2. ed. Washington, DC: USDA, 1999.

VERHOEVEN, E.; SIX, J. Biochar does not mitigate field-scale N_2O emissions in a northern California vineyard: an assessment across two years. *Agriculture, Ecosystems & Environment*, v. 191, n. 1, p. 27-38, 2014.

WOLFF, M. W.; ALSINA, M. M.; STOCKERT, C. M.; KHALSA, S. D. S.; SMART, D. R. Minimum tillage of a cover crop lowers net GWP and sequesters soil carbon in a California vineyard. *Soil and Tillage Research*, v. 175, n.1, p. 244-254, 2018.

WONG, C. T. F.; FALCONE, M.; RICH, G.; STUBLER, C.; MALAMA, B.; LAZCANO, C.; DECOCK, C. Short-term effects of increasing compost application rates on soil C and greenhouse gas (N_2O and CO_2) emissions in a California central coast vineyard. *Frontiers in Environmental Science*, v. 11, e1123510, 2023.

ZAMAN, M.; KLEINEIDAM, K.; BAKKEN, L.; BERENDT, J.; BRACKEN, C.; BUTTERBACH-BAHL, K.; CAI, Z.; CHANG, S. X.; CLOUGH, T.; DAWAR, K.; DING, W. X.; DÖRSCH, P.; MARTINS, M. dos R.; ECKHARDT, C.; FIEDLER, S.; FROSCH, T.; GOOPY, J.; GÖRRES, C-M.; GUPTA, A.; HENJES, S.; HOFMANN, M. E. G.; HORN, M. A.; JAHANGIR, M. M. R.; JANSEN-WILLEMS, A.; LENHART, K.; HENG, L.; LEWICKA-SZCZEBAK, D.; LUCIC, G.; MERBOLD, L.; MOHN, J.; MOLSTAD, L.; MOSER, G.; MURPHY, P.; SANZ-COBENA, A.; ŠIMEK, M.; URQUIAGA, S.; WELL, R.; WRAGE-MÖNNIG, N.; ZAMAN, S.; ZHANG, J.; MÜLLER, C. *Measuring emission of agricultural greenhouse gases and developing mitigation options using nuclear and related techniques*. Vienna: Springer, 2021.