Inoculation of Arbuscular Mycorrhizal Fungi in Under-Vine Cover Crops for Sustainable Vineyards Development

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Abstract

Viticulture is a major economic sector in Europe. However, the raise of new challenges, such as the new regulations towards a limitation on the use of several agrochemicals, to new market demands, and to environmental and climatic awareness, forces adaptations on viticulture practices. Shift to sustainable vineyard management practices, such as the use of cover crops and arbuscular mycorrhizal fungi (AMF), plant mutualistic fungi, represent an attractive approach to respond to some of the challenges of modern viticulture. In this work, the benefits of the installation of cover crops as an eco-friendly soil management technique, with special attention to under-vine cover crops are reviewed. In addition, the advantages of AMF to improve agroecosystem functions and to promote higher grapevine performance will be reviewed.

On the one hand, cover crops are widely known to prevent erosion, enhance soil physical and chemical properties, including nutrient cycles, as well as soil biological diversity and activity. Furthermore, the installation of cover crops in vineyards may improve grapevine nutritional status, control their vigour, and can prevent pests and diseases by providing food and shelter to antagonists of insect pests, nematodes, and pathogens. On the other hand, AMF improve grapevine nutrition, growth, and tolerance against a variety of biotic and abiotic stress factors, such as root diseases, water stress, soil salinity, and heavy metals toxicity. The mycorrhizal extraradical mycelium that extends in the soil also contributes to ameliorate soil properties such as particle aggregation, water retention, and soil stability.

Using herbaceous plants as cover crops in vineyards favours the development of AMF, and therefore, the inoculation of AMF in under-vine cover crops can represent a novel sustainable soil management practice for vineyards with low propagule content or facing soil degradation.

Key Words: Grapevine (*Vitis Vinifera* L.), climate change, vegetative cover, symbiosis, inoculation.

Resumo

A viticultura é um setor economico importante na Europa. No entanto, a viticultura vê a necessidade de se adaptar a novos desafios, tais como novas regulamentações para a limitação do uso de vários agroquímicos, novas demandas do mercado e a crescente consciência ambiental e climática. A mudança da viticultura para práticas sustentáveis de gestão da vinha, como o uso de culturas de cobertura e fungos micorrízicos arbusculares (FMA), fungos mutualísticos das plantas, representam uma abordagem atraente para responder a alguns dos desafios da viticultura moderna.

Por um lado, as culturas de cobertura são amplamente conhecidas por prevenir a erosão, melhorar as propriedades físicas e químicas do solo, incluindo os ciclos de nutrientes, bem como a diversidade e atividade biológica do solo. Além disso, a instalação de plantas de cobertura nos vinhedos pode melhorar o estado nutricional da videira, controlar seu vigor e prevenir pragas e doenças, fornecendo alimento e abrigo para antagonistas de pragas de insetos, nematoides e patogénicos. Por outro lado, os FMA melhoram a nutrição, o crescimento e a tolerância da videira contra uma variedade de fatores de estresse biótico e abiótico, como doenças das raízes, estresse hídrico, salinidade do solo e toxicidade de metais pesados. O micélio extrarradicular micorrízico que se estende no solo também contribui para melhorar as propriedades do solo, como agregação de partículas, retenção de água e estabilidade do solo.

O uso de plantas herbáceas como plantas de cobertura em vinhedos favorece o desenvolvimento de FMA e, portanto, a inoculação de FMA em plantas de cobertura sob a linha da vinha pode representar uma nova prática de manejo sustentável do solo para vinhedos com baixo teor de propágulos ou em degradação do solo.

Neste trabalho, são revistos os benefícios da instalação de plantas de cobertura como uma técnica de manejo do solo sustentável, com especial atenção às plantas de cobertura localizadas na linha das videiras. Além disso, as vantagens de FMA para melhorar as funções do agroecossistema e promover o melhor desempenho da videira serão revisadas.

Palavras-chave: Videira (*Vitis vinifera* L.), mudanças climáticas, cobertura vegetal, simbiose, inoculação.

Extended Abstract

The grapevine provides good agronomic results in different types of soil and adapts well to different climates, i.e., it is characterized by having fine ecological adaptability. Nevertheless, crop performance, yield production, and eventually wine quality depend on various factors, such as climate, soil biota, and cultural practices. For this reason, it is highly challenging for grape growers to satisfy grapevine productive needs, while considering economic and environmental issues all along with mitigating consequences of extreme new weather events and pathogenic infection arising in the last years.

It is a reality that a general concern is rising about water use efficiency, better pest and chemical fertilizers management, land erosion, and the determination for sustainable practices. Hence, in the current context of climatic and edaphic threats, it is crucial to expand knowledge on the most suitable vineyard management practices that can be conducted to satisfy human needs as well as environmental and economic demands.

In this context, the use or correct management of arbuscular mycorrhizal fungi (AMF), in agricultural soils, represents an eco-friendly approach. These fungi create symbiotic relationships with roots of more than 80% of terrestrial plants, being so often fundamental for normal plant growth and development. In fact, arbuscular mycorrhiza is frequently considered one of the most important symbioses on the planet, providing crucial ecosystem support.

The prime strategy to enhance AMF contribution to plants is the inoculation of their propagules (e.g., spores, colonized root fragments) in the soil or in contact with roots, which allows the most appropriate fungi selection for each condition. In fact, there are already many companies producing selected AMF commercially. Three techniques commonly used for introducing mycorrhizal fungi in vineyards are: pre-inoculation before planting; direct field inoculation; and inoculation through mycorrhizal donor plants (MDP).

Cover crops are widely used in agriculture/viticulture to improve soil quality, including microbial diversity and soil nutrient content. However, they may also compete for water with the main crop, although a detailed comprehension of the interaction among different environmental and agronomic practical factors is needed to optimize this practice. Due to their overall benefits green covers report to sustainable viticulture, cover crops are excellent candidates for being MDP for grapevines, allowing to combine the benefits that AMF inoculation for grapevines with the advantages that cover crops can provide to vineyards

This work aims to review and compose knowledge about AMF and vineyard cover crops, as well as the evaluation of a recently proposed AMF inoculation method through MDP consisting of under-vine cover crops, that can be implemented as a sustainable soil management technique.

Resumo Alargado

A videira apresenta bons resultados agronómicos em diferentes tipos de solo e adapta-se bem em diferentes climas, ou seja, caracteriza-se por possuir uma boa adaptabilidade ecológica. No entanto, o desempenho da cultura, o rendimento da produção e, eventualmente, a qualidade do vinho dependem de vários fatores, como clima, biota do solo e práticas culturais. Por esta razão, é altamente desafiador para os viticultores satisfazer as necessidades produtivas da videira, considerando questões econômicas e ambientais, juntamente com as consequências mitigadoras de novos eventos climáticos extremos e infeções patogênicas surgidas nos últimos anos.

É uma realidade que cresce uma preocupação pelo correto e eficiência do uso da água, melhor gestão de pragas e fertilizantes químicos, erosão da terra e a determinação de práticas sustentáveis. Assim, no atual contexto de ameaças climáticas e edáficas, é fundamental ampliar o conhecimento sobre as práticas de manejo da vinha mais adequadas que podem ser conduzidas para satisfazer as necessidades humanas, bem como as demandas ambientais e econômicas.

Nesse contexto, o uso e/ou correto manejo de fungos micorrízicos arbusculares (FMA), em solos agrícolas, representa uma boa abordagem a nível ecológico. Estes fungos criam relações simbióticas com raízes de mais de 80% das plantas terrestres, sendo muitas vezes fundamentais para o crescimento e desenvolvimento normal das plantas. De facto, a micorriza arbuscular é frequentemente considerada uma das simbioses mais importantes do planeta, fornecendo suporte crucial ao ecossistema.

A principal estratégia para aumentar a contribuição de FMA para as plantas é a inoculação dos seus propágulos (por exemplo, esporos, fragmentos de raízes colonizadas) no solo ou em contato com as raízes, o que permite a seleção de fungos mais adequada para cada condição. De facto, já existem muitas empresas que produzem comercialmente FMA selecionados. Três técnicas comuns utilizadas para a introdução de fungos micorrízicos nas vinhas são: pré-inoculação antes do plantio; inoculação direta em campo; e inoculação através de plantas doadoras de micorrizas (PDM).

As culturas de cobertura são amplamente utilizadas na agricultura/viticultura para melhorar a qualidade do solo, incluindo a diversidade microbiana e o teor de nutrientes do solo. No entanto, estas também podem competir pela água com a cultura principal, embora seja necessária uma compreensão detalhada da interação entre diferentes fatores práticos ambientais e agronômicos para otimizar a prática. Devido aos seus benefícios globais as coberturas verdes integram-se na viticultura sustentável, as plantas de cobertura são excelentes candidatas a PDM para a videira, permitindo combinar os

benefícios da inoculação de FMA para a videira com as vantagens que as coberturas podem proporcionar aos vinhedos

Este trabalho tem como objetivo revisar e compor o conhecimento sobre FMA e plantas de cobertura de vinhedo, bem como a avaliação de um método de inoculação de FMA recentemente proposto por meio de PDM composto por plantas de cobertura na linha das videiras, que pode ser implementado como uma técnica de manejo sustentável do solo.

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ABBREVIATIONS LIST

→ ABA – Abscisic Acid
→ AMF – Arbuscular Mycorrhizal Fungi
→ BAS – Branched Absorbing Structures
→ B – Boron
→ CI – Cool Night Index
→ CompI – Composite Index
→ Cu - Copper
→ DI – Dryness Index
→ ERM – Extraradical Mycelium
→ EU – Europenean Union
→ FAO – Food & Agriculture Organisation
→ Fe – Iron
→ G. – *Glomus*
→ GHG – Greenhouse Gas
→ HI – Hugling Index
→ Hyl - Hydrothermal Index
→ IFOAM – International Federation of Organic Agriculture Movements
→ IRM – Intraradical Mycelium
→ K – Potassium
→ L. – Linnaeus
→ LHS – Life-history strategies
→ MDP – Mycorrhizal Donor Plants
→ Mn - Magnesium
→ N – Nitrogen
→ OIV – International Organisation of Vine and Wine
→ OTUs – Operational Taxonomy Units
→ P – Phosphorus
→ Pi – Inorganic Phosphorus
→ Po – Organic Phosphorus
→ Poly-P – Polyphosphate
→ PSB – Phosphate Solubilizing Bacteria
→ R. – *Rhizoglomus*
→ SOM – Soil Organic Matter
→ S – Sulfur
→ Var. – Variety
→ Zn - Zinc

Introduction

Climate change, the ecological catastrophe, and human needs have all combined to make sustainable agriculture the big vision for the next generation of farmers. Our planet calls for a change, whilst products' demands keep increasing. Agriculture is feeling the inevitability of implementing green practices, either by awareness and concern about this land of ours, or even, by the "fashions" of the biological and sustainable products.

Agriculture is one of the main greenhouse gases (GHG) emitters, is also responsible for the pollution derived from excessive use of agrochemicals (e.g. synthetic fertilizers, pesticides, herbicides) deforestation and intensive use of big land surfaces. In view of this issues, the biologist Paul Ehrlich speculated that a mass famine would end the exponential population growth that our world is facing since the last century (Ehrlich, 1997). However, Ehrlich is probably astonished by the production capacities we have achieved today, which are due to several scientific and technological advances in crop management practices/techniques and varietal selection, but also to new discoveries made during what is often referred to as The Green Revolution. Indeed, between 1950 and 1960 there was a major evolution and knowledge advance in chemical pest control and in the use of synthetic fertilizers, such as nitrogen (N), phosphorus (P), and potassium (K) (Tilman et al., 2002). In fact, the use of synthetic fertilizers represents a more immediate form to fulfil crops' demands and increase their efficiency, which consequently lead to a substantial increase in crop production globally.

Most Non-organic fertilizers contain N, P, K, and their production industry is a source of radionuclides and heavy metals (Savci, 2012). Regarding N, which is essential for living organisms, it is present in abundance in our ecosystem, mostly as a colourless and odourless gas – N_2 – that composes about 78% of the earth's atmosphere (National Geographic Encyclopaedia - National Geographic Society, 2019). However, plants and animals are not capable of using it directly in the form of gas. Animals find their nutrients in food, whereas plants need the presence of N in other (reactive) forms in the soil (NO_3 or NH_4), but their levels are often insufficient for optimal crop growth.

Although it is now chemically produced in huge quantities, even surpassing all limits of ecosystem cycles, N was once a limited element, and between the 19th and 20th centuries it was believed that its natural sources were running out. However, in the beginning of the 19th century, thanks to the breakthrough discovery of Haber-Bosh process, the pioneer technology to produce synthetic nitrogen fertilizers (Smil, 2004), N is no longer a limiting resource, and world population has continued growing exponentially, contradicting Ehrlich's predictions (Erisman et al., 2008) (Figure 1). In fact, according to STATISTITA report (Fernández, 2021), the global consumption of N fertilizers in 2019 reached nearly 108 megatons, compared to 18.7 megatons in 1965. Nevertheless, Lassaletta et

al. (2014), based on FAO data, concluded that only 47% of the N applied was used by crops. A big portion of it is leached as NO_3, denitrified, or emitted as NH_3.
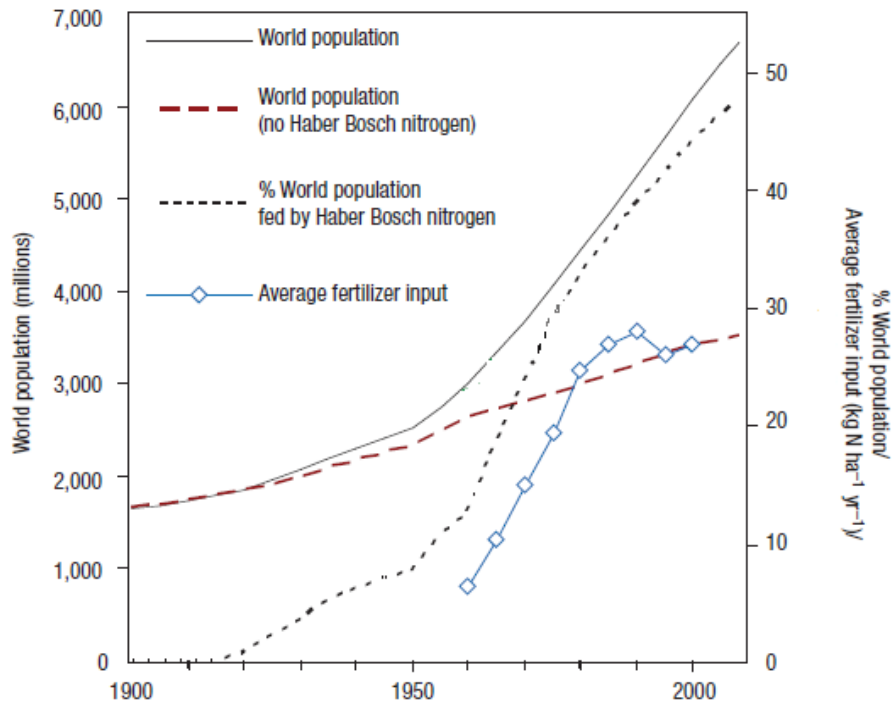
Figure 1- Human population and nitrogen use – trends during the twentieth century. A comparison of world population evolution with and without Haber Bosh process, i.e., syntactic nitrogen production. Adapted from Erisman et al., 2008

In the same report, substantial increases on the use of other macronutrient-based fertilizers were also recorded. For instance, Nitrogen fertilizer demand peaked at 46.3 million metric tons in 1965. By 2019, this figure had risen to more than 190 million tons. Phosphorus pentoxide, with a consumption of 16.02 megatons in 1965, that expanded to 45.32 megatons in 2019 (Fernández, 2021).

Nevertheless, although the technical advances in the production and use of synthetic fertilizers have been crucial to greatly increase crop production and to bring enormous economical profits, their use is becoming more and more controversial, due to the large impacts on the environment. This is in part because a significant portion of the nutrients applied in crops are not profited by them and run off into water and natural reservoirs. For this reason, regulations are becoming more restrictive with a view of responsible agriculture.

In addition, consumers are also changing their habits, and are becoming progressively more aware of the ecological footprint of the food they buy. Studies show that buyers are willing to pay considerably more for organic products (Goldman and Clancy, 1991; Yiridoe et al., 2005). Civil movements and actions are also increasingly occurring, with health, ecology, fairness, and care as the main principles, as the International Federation of Organic Agriculture Movements (IFOAM)

established (Luttikholt, 2007), with the vision of growing food in a way that sustains the health of the people and the planet. For all those reasons, sustainable and organic agriculture have considerably grown in the last years. Organic agriculture is recognised as the essential procedure to harmonize crop production, biodiversity, and environmental conservation.

Viticulture is also feeling the new trends in agriculture. In conventional viticulture, grape-growers' work consists of mainly of ensuring plant health, production and maximum economic profitability, which requires large energy, chemical inputs (for fertilization, weed management, pest control) and technical proficiency (e.g., for providing appropriate water demand to plants). However, the new legislation on agrochemical uses, the growing consumers/farmers consciousness on environmental sustainability, and the importance of wine quality is leading to a transformation of viticulture practices. Many alternatives have been studied and developed, with the view of balancing all the objectives at production, environment, plant health and sustainability levels.

In this context, the use of cover crops in vineyards has been increasingly growing in the last decades (Pardini et al., 2002). They have become an important component for sustainable and organic agriculture, since green cover vegetation may act as a great soil and ecosystem quality conservator.

Similarly, grapevine inoculation with arbuscular mycorrhizal fungi, soil-inhabiting fungi forming mutualistic relationships with grapevines as well as for many other plant species (Smith and Read, 2008), is a practice that is growing in interest among grapevine growers. Arbuscular mycorrhizal fungi can provide many benefits to plants: they play a crucial role in grapevine growth and nutrition, and they improve plant tolerance to biotic and abiotic stress factors, reducing the need for fertilizers and pesticides (Smith and Read, 2008, Trouvelot et al. 2015). However, the success of field inoculations may depend on the method. Recently, a new inoculation strategy was proposed: AMF inoculation through mycorrhizal donor plants (MDP) planted on the under-vine space, as under-vine cover crops.

In this work, the impact of the use of cover crops in vineyards will be reviewed, with a special focus on their influence on AMF populations. Furthermore, a suggestion of a new way of implementing cover crops in the under-vine space will be made: the use of mycorrhiza-inoculated under-vine cover crops.

1. Viticulture

Viticulture is a millenary practice. Grapevine (*Vitis Vinifera* L.) was among the first fruit crop species to be domesticated. Besides the important crop that represents, the grapevine is also connected with ancient habits and traditions that followed the cultural evolution of the peoples, due to winemaking, its principle final product (McGovern, 2004; This et al., 2006). With long history and culture attached, vineyard propagation was promoted by Greeks and Romans with a strong

establishment in Europe – the "old world" - and later spread worldwide to the so-called "new world" (North and South America, Australia, New Zeeland, South Africa, and China) (Reynier, 2004).

Vitis Vinifera, from the family Vitaceae, is nowadays the most economically important crop worldwide (Keller, 2010), cultivated in six out of seven continents. There is nearly 7.5 million ha of vineyards' surface area, dated in 2016, according to the International Organization of Vine and Wine database (OIV, 2016), and in 2019, it was estimated a worldwide wine production of 292.3 million hL (OIV, 2019). European Union is the leader of the production of grape and wine, encompassing more than 50% of the worlds' vineyard surface area (OIV, 2019).

In Portugal, winemaking is a dominant sector of great socio-economic significance. With a total of 14 grape-growing regions and a total vineyard surface area that exceeds 190 thousand hectares (IVV, 2020), the country covers a broad array of edaphoclimatic conditions, diverse climates, soil types, and geomorphological features, comprising unique "terroirs". Among the most unique and highly recognized *terroirs* in Portugal is for example the Douro Valley. This Portuguese region is the oldest demarcated and regulated wine region that contains the larger world's mountain vineyard surface area, and it is a UNESCO World Heritage site. In the valley, there is a special climate formed due to the Alvão, Marão, and Montemuro mountains, that act as a barrier to the west and shield from the humid wind of the Atlantic Ocean, that are at the bases of the renowned wines of the region. Moreover, due to the mountains, there is a diversity of mesoclimates. Another example is the Alentejo, another extremely important wine region in Portugal, which although being more homogenous in terms of climate and soils type, with mainly flatlands, it is divided into eight subregions, where each of them offers distinct wines (Fraga et al., 2012).

1.1. Viticulture and Climate Change

Climate change is in fact a problem that encompasses many factors and consequences, such as raised temperatures and less water availability. In Portugal and in the rest of Europe with Mediterranean climates, these changes are becoming evident, with higher temperatures and rainfall increasingly variable (Giorgi and Lionello, 2008).

Climate change is, in fact, a natural process and it refers to alterations in weather and temperature patterns, at a long-term level. However, human's actions since the industrial revolution have been greatly altering the ecosystem cycles and creating dangerous impacts globally, primarily by GHG emissions, which is causing a global temperature increase. Greenhouse gas (above all, carbon dioxide and methane) are emitted mainly by industry, energy, and agriculture, among other anthropogenic activities. These alterations are being felt at various levels. As a result of GHG emissions, the Earth is 1ºC warmer than before industrial revolution (Van Leeuwen and Darriet, 2016).

Nevertheless, temperature is not homogenous throughout the globe, reflecting higher temperatures in some regions and unbalanced weather events such as intense droughts, floods, severe fires, and catastrophic storms, in other regions. Furthermore, other negative consequences such as the melting of polar ice, rising sea level and a worrying decline of biodiversity are happening in the last decades, with disastrous consequences for the ecossystem and for the population of several countries

Overall, grapevine grows in areas with warm dry summers and mild wet autumns-winters, characteristic of Mediterranean climate, with optimum temperatures encompassing 25-30ºC for growing season. Therefore, follows a limited geographic localization with suitable thermal zones – isotherms between 10-20ºC, i.e., latitudes 30 to 50ºN and 30 to 40ºS, matching the temperate climate areas (Reish et al., 2012). However, altered weather patterns due to climate change (e.g. reduction of precipitation, heatwaves and extreme high-temperatures events, global warming) represents a big obstacle for grape growers, since grapevine, as many other crops, is highly dependent on climatic and weather conditions (Jackson, 1993). In fact, among all influencing factors in grapevine production, climate is indeed considered the major agent, affecting yield and grapevine physiology and phenology, even more than other factors such as grape variety and agricultural techniques (Jones and Davis, 2000; van Leeuwen et al., 2004; Santos et al., 2011). For instance, shifts in grapevine phenological stages due to climate change are being reported in recent studies, such as the shortening of some stages and earlier onsets (Keller, 2010; Bock et al., 2011; Alikadic et al., 2019; Venios et al., 2020) (Figure 2). In fact, grapevine phenology is highly dependent on thermal conditions (Mandelli et al., 2005; Greer and Weston, 2010), and therefore, under non-ideal conditions, i.e., extreme, or unusual temperatures and radiation throughout the growing season, berry health and composition may be impaired, influencing olfactory and gustatory notes. Moreover, when excessively high temperatures are achieved during the growing season, respiration rates increase, compromising plant photosynthesis, proper metabolism, and berry development, ultimately affecting yield and quality. Furthermore, winter chilling is also very important for bud dormancy (Bates et al., 2002), and later, in spring, a base temperature of ca. 10ºC is required to break its dormancy period and onset the growing/vegetative cycle.

Climate change's consequences have been observed and are predicted to be accentuated in the future. In a study of climate change projections, Fraga et al. (2012), evaluated five bioclimatic indices in continental Portugal, and predicted that climate change would induce to alterations over the next decades. Hugling Index (HI), highly correlated with grapevine thermal demands and therefore, with phenological events, and Cool Night Index (CI) indicated significant increases in both parameters (HI and CI). Furthermore, a decrease in rainfall patterns pointed to intensified water stress conditions, correlated with the decrease of Dryness Index (DI), as well as a decrease in Hydrothermal Index (HyI). This last factor was positively correlated with the risk of pest incidence. Ultimately, Composite Index (CompI) evaluation predicted the changes that may occur in Portuguese areas regarding the capacities

for grapevine production and showed that large Portuguese areas would become less appropriate, mainly in south-eastern regions, like Alentejo. Other studies had the same conclusions about the threats that human-driven climate changes represent in viticulture, in terms of productivity and product quality (Duchene and Schneider, 2005; Stock et al., 2005; Neumann and Matzarakis, 2011).

Regarding water availability, climate model projections indicate increasingly extreme precipitation events in the United States (U.S. Global Change Research Program, 2014) and Europe (Zolina, 2012; Howarth et al., 2019; Hosseinzadehtalaei et al. 2020), as well as unsteady rainfall patterns (Vaden Heuvel and Centinari, 2021). The consequences would be highly detrimental to plants and soils, manly in productions with bare soils, i.e., without green covers, that could present higher risk of erosion and nutrient runoff, with the consequent prejudice in nutrient availability.

1.2. Sustainable Vineyard Management Practices to Mitigate the Impacts of Climate Change and Environmental Degradation

Conventional vineyard management practices are usually characterized by the use of methods for controlling pests and grapevine diseases and are primarily based on the use of synthetic products. Weed control is done by herbicide applications or by soil tilling, while soil fertilization is conducted by using mineral fertilizers. Therefore, they require large energy and chemical inputs for grapevine growth and productivity to achieve maximum economic profit. However, these management practices have raised consumers and grape grower's concerns in the last years due to the environmental consequences that some of them may entail. Furthermore, regulations are becoming more restrictive with a view of responsible agriculture and viticulture. For instance, in December 2018, the EU restricted the use of copper pesticides to prevent its accumulation in the soil.

Organic viticulture arises as an answer to climatic awareness, market demands/fashions, and EU regulations towards a limitation of many agrochemicals. In addition, these transitions also occurs regarding agronomical impacts of traditional management practices namely on grape phenology and ripening (Stock et al., 2005; Xu et al., 2012). However, other several grape growers may see the shift to an environmentally friendly production as a possibility to escalate their sales and prices (Villanueva-Rey et al., 2014).

Fundamentally, organic viticulture is characterized by a prohibitive use of synthetic fertilizers and herbicides, a conscious cultivation of the vineyard, in order to promote soil health and fertility, and a crucial respect for the natural cycle of the grapevine. The rate of conversion to organic management exploded during this century, with an average of 13% of certified organic vineyard surface area increase per year from 2005 to 2019, and a total of 454 kha of certified organic vineyards estimated for that last year (OIV, world database, 2019). Although the idea of organic viticulture is

appealing, the obstacles are frequently difficult (lack of technical knowledge and suitable machinery, expensive products), hence many grape growers decide not to make the transition to organic management, but instead, to progressively adopt sustainable practices inspired in organic farming.

It is believed that the adoption of environmentally sustainable vineyard management practices will contribute to and improvement of the agroecosystem functioning that will lead to an enhancement of grapevine performance, productivity, and resilience towards biotic and abiotic stress factors, such as the ones derived from climate change. Among these, the establishment of cover crops can be an attractive soil management strategy to help on mitigating climate change effects on vineyards. Cover crops are a good alternative in some regions, especially in places where there is risk of high rainfalls, erosion, or floods or where grapevines grow very vigourously. However, special care needs to be taken when implementing them in the Mediterranean and semi-arid soil/regions, because of potential competition with scarcer water resources.

2. Cover Crops

Cover crops are plants used to cover bare soils in agricultural productions, that may carry numerous benefits for both, the main crop and the ecosystem. Cover crops differ from cash crops, since the aim of their establishment is to protect and enrich the soil, instead of obtaining a product from them. Cover crops may coexist with the main crop (e.g. in the case of perennial cash crops and interrow cover crops) or can be separated in time (e.g. winter cover crops and spring-summer cash crops) (Kocira et al., 2020; McClelland et al., 2021).

Green covers can be based on native plant species, spontaneously growing in the area, by merely following the strategy or no-tillage and non-use of herbicides; or can be purposely planted, having in this case, the advantage of most suitable species selection and the disadvantage of the work that is added to it (Frey and Moretti, 2019).

In both cases they are widely known for decreasing the risk of erosion (Battany and Grismer, 2000; Le Bissonais et al., 2004; Gomez et al., 2011; Bagagiolo et al., 2018), for their ability to improve soil properties, including greater surface strength, water retention and infiltration (Lopes et al., 2004), and nutrient availability (Folorunso et al., 1992; Lopes et al., 2004; Oehl and Koch, 2018). Moreover, with a proper management, they can reduce costs, due to reduced herbicides and possible fertilizers application and enhanced cash crop yield. Additionally, they can even create new revenue streams from haying and grazing (Lichtenberg, 2004; Wang et al., 2021).

In vineyards, the green cover species can be placed on the under-vine area -beneath the grapevine's lines or in the inter-row space. In viticulture, the conventional vineyard floor management

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practices include the combination of soil tillage and herbicide application to maintain a completely bare soil (Quecedo et al., 2012; Chou and Vaden Heuel, 2018), although in various regions worldwide the use of cover crops in the inter-row space and the use of herbicides in the under-vine area is becoming very popular as well. Cover crops are indeed an attractive form of soil surface management in vineyards due to the benefits they bring, particularly in lands with excessive soil moisture (Figure 4).

Although in general, the use of cover crops is a clear effective practice with benefits that mostly overcome disadvantages, in some conditions, their establishment may not produce the expected results (Salazar and Melgarejo, 2005). For example, when water and nutrients are limited, cover crops can lead to competition with the main crop for those resources (Morlat, 1987; Moulis, 1994; Lopes et al., 2004: Celette et al., 2008). In fact, the growing needs of both species (Celette et al., 2008; Celette et al., 2009) and the potentially high total evapotranspiration can lead to adverse effects on grapevine development, vigour, and yield (Rodriguez-Lovelle et al., 2000; Guerra and Steenwerth, 2012; Lopes et al., 2011) and accelerate the progress of water stress and N deficiency (Celette et al., 2009, Taskin et al., 2021). In Mediterranean non-irritated regions, which is the case of non-irrigated Portuguese vineyards, with lack of summer rainfall and high levels of evaporative demand, the use of cover crops has been restricted due to the mentioned competition. Nevertheless, some studies conducted in Mediterranean climates, showed that the use of cover crops is advantageous (Abad et al., 2021). For instance, in Portugal, a study on cover cropping in a sloping non-irrigated vineyard by Lopes et al. (2008), showed that permanent vegetation and sown cover crops enhanced grape must composition, as a consequence of the competition between both crops.

Thus, in-depth knowledge of the impact that cover crop plant species may cause on the grapevine's growth and reproductive development must be assessed, for their optimal implementation and for obtaining the expected outcome in the vineyard.

2.1. Planted Cover Crops Species

With aim of comprehending how to take the maximum advantage from cover crops, it is essential to understand the different characteristics of the green cover species that can grow in a vineyard, the living mulch in grapevine's soil. Different species of cover crops i.e., with their own particular phenological differences, physiognomies, needs and life habits, can trigger distinct responses in the main crop (Guerra and Steenwerth, 2012; Muscas et al., 2017; Abad et al., 2021), can alter soil characteristics (e.g. soil water and nutrient dynamics (Perkons et al., 2014) and they can influence the agroecosystem itself (e.g. animal and microbial populations, with potential consequences on the incidence of insect pests and diseases). For instance, dissimilar root properties (type, depth, and density) may be a factor in cover crop effectiveness to control erosion (De Beats et

al., 2007), since fibrous root systems have better erosion-reducing potential than tap root systems (De Beat et al., 2007, 2011).

The most frequently used cover crops species are cereals and grasses, belonging to the Poaceae family, and legumes (Fabaceae family) (Guerra and Steenwerth, 2012), but the options are various. Indeed, usually, a mix of leguminous and non-leguminous species is selected to establish cover crops. On the one hand, grass-cover crops have shown to be effective to promote soil aggregation, by virtue of their fibrous roots (Colugnati et al., 2004), and on the other hand, legume species can benefit the main crops by supplying N to them due to the biological N fixation (due to the symbiosis with Rhizobia) that happens in their roots (Vrignon-Brenas et al., 2016).

Wheaton et al. (2008) tested different soil management treatments in an irrigated vineyard in Australia and observed that among the Poaceae family plants, ryegrass led to better results in soil microporosity and in grapevine root growth than wheat straw, possibly due to a better root system, i.e., ryegrass improved soft soil depth and enhanced soil aggregation possible through a promotion of earthworm activity. An additional example was provided by Tisdall and Oades (1979) study, which showed that ryegrass' root system supported a wider AMF population in the soil, with potential benefits at the plant level and promoting greater aggregate stability in the soil, compared to white clover (Fabaceae family).

In a different study, Chou and Vanden Heuel (2018) also showed differences in the effect of under-vine cover crops when distinct plant families (Fabaceae, Asteraceae, and Brassicaceae) were planted in the vineyard. Chicory (Asteraceae family) influenced vine vigour, as it happened in previous studies (Wheeler et al., 2005). Chicory and tall fescue (Poaceae family) reduced pruning weight. Each cover crop reduced the fruiting zone leaf layer number, although they had little to no impact on berry composition and no effect on yield per vine. Regarding noted improvements in soil properties, most of the cover crops showed benefits, while tillage radish (also known as daikon radish) (Brassica family) did not.

2.2. Cover Crops' Benefits – Ecosystem Services

Improving ecosystem services is a major priority in agricultural production. These are commonly defined as benefits that nature provides, directly or indirectly, to sustain human life and agricultural productivity. These include a combination of processes such as nutrient cycling, soil formation, water regulation and natural control of pests, that will benefit crop production.

Cover crops are known for their role in enhancing ecosystem services, due to their action as living soil cover. Cover crops protect and improve soil quality and fertility, reduce the risk of erosion, enhance soil organic matter and nutrient content, and improve microbial activity in the soil. Hence,

this sustainable management technique is of high importance to the agroecosystems, including the one in vineyards (Figure 4, Table 1).
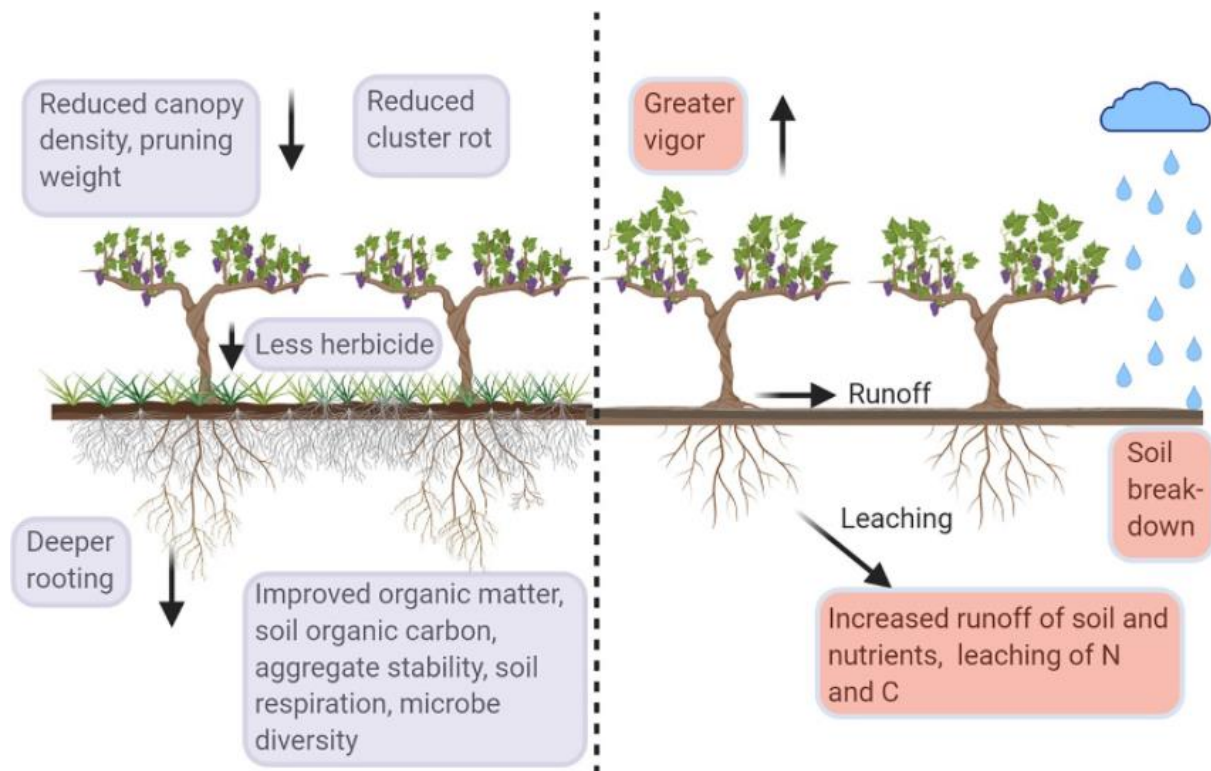
Figure 1 - Effects of cover crops as soil management technique compared to bare soil. Grey boxes represent ecosystem services provided by cover crops and red boxes the ecosystem disservices. **Source**: Vanden Heuvel and Centinari*, 2021*

2.2.1. Reduce the Risk of Erosion

Soil is an essential element in the ecology of the planet, the foundation of several habitats and with many ecological functions that create a balance among the earth, through biotic and abiotic factors. Soils play a key role in the Earth's ecological system, as they are the foundation of water filtration, the transformation of organic matter into nutrients, gas exchange, and carbon sequestration (Cerdà et al., 2007).

Agricultural soils are considered to be relatively degraded lands from the moment that forest and other natural lands are removed to establish the first crops plantations. Indeed, nowadays the creation of new agricultural fields is among the most important operations that aggravate the risk of erosion and soil deterioration (Cerdà et al., 2007, 2009). In addition, due to the use of fertilizers and agricultural techniques, such as ploughing, soil structure is further compromised. Erosion is a significant concern in agriculture (Pimentel et al., 1995) as it compromises land stability and quality, depletes soil fertility, alters its depth and infiltration capacity limiting water availability (Sofia et al., 2017; Vaudour et al., 2017), and triggers desertification (Oldeman, 1994). In the most severe cases,

soils can be highly or irreversibly damaged. Mediterranean agricultural lands are especially at risk, due to the intense rainfall events that frequently occur. This is also true for viticulture, which is highly influenced by soil configuration, structure, and health (Wheaton et al., 2008; Laudicina et al., 2016) for an optimal grapevine vigour and performance (Calleja-Cervantes et al., 2015; Laudicina et al., 2016; Novara et al., 2018). Studies on the influence of soil erosion in viticulture are scarce, but it has been documented that it supposes economic costs (Galati et al., 2015), as it brings, indirectly, yield and grape quality losses, due to nutrient losses (namely N) that highly influence shoot and root growth (Ferreira et al., 2018).

One of the main advantages of cover crop establishment is a reduction of the erosion caused mainly by water and wind, by protecting the soil against stronger impacts acting as a shield (Battany and Grismer, 2000; Malik et al., 2000; Kaspar et al., 2001; Ryder and Fares, 2008), and by interfering with the runoff at the surface of the soil, acting as a flow retarding agent (Styczen and Morgan, 1995). Furthermore, cover crops' root system contributes to soil stability, making it more resistant to erosion (Morgan, 2005).

Data on runoff rates and soil losses in vineyards with cover crops when compared to conventional tillage technique and bare soil demonstrate, that cover crops are important management technique in viticulture to reduce land degradation (Leys et al., 2007; Novara et al. 2011; Morvan et al., 2014; Rodrigo-Comino et al., 2018). Abad et al. (2021), in a cover crops review, collected data from previous studied carried throughout Europe, mostly Mediterranean climate conditions, and observed that in herbicide and tillage treatments, there was higher soil losses. These cases showed numbers from 7 to 20.7 Mg/ha-year, with the exception tilled plots in Madrid, Spain (Ruiz-Colmenero et al., 2011) where it was only quantified 0.008 Mg/ha-year of soil. Regarding runoff rates, on average, were greater in tilled control plots (21.8 %) than in grass cover crop plots (11.8 %). The authors concluded that continuous perennial cover cops have better results than temporal planted vegetation, hence the period of plant cover affects soil losses as well.

In general, according to Blanco-Canqui et al. (2015), cover crops can runoff by 80% of values, and decrease up to 96% of eroded soil. Erosion causes soil loss, as well as carbon and nutrient losses, which are pulled via soil particles (Abad et al., 2021).

2.2.2. Soil Health and Quality

Soil health is understood as soil ability to function as a vital living system, involving its structure, water, and nutrient cycles, in order to maintain and improve the productivity, as well as the development of the fauna and flora that are included within (Doran and Zeiss, 2000). Soil health and quality are major attributes in agriculture and viticulture (Laudicina et al., 2016). Soil organic matter

content and nutrient cycling are a key aspects in soil health, which are often compromised due to pollution, the excessive use of chemical fertilizers and land wear (Sahu et al., 2017).

Cover crops are known for their contribution to soil health by various mechanisms. The root system improves soil structure and aggregation and supports nutrient and water cycling. In addition, cover crops enhance SOM a microbial activity. Hence, green covers provide great ecosystem benefits that support fertility and soil stabilization, contributing to soil health. Moreover, it is a soil management practice that opposes to tillage, which in turn considerably impairs the physical and chemical properties of the soil (Kraut-Cohen et al., 2019).

The root system of green cover plants improve the physical environment due to alleviation in soil compaction (Chen and Weil, 2010), the establishment of stable aggregates (Bartoli and Dousset, 2011; Lopez-Pineiro et al., 2013; Ruiz-Colmenero et al., 2013; Belmonte et al., 2018), increased hydraulic properties (improved infiltration rates and water holding capacity) (García-Díaz et al., 2018), and even by a more balanced soil temperature (Teasdale and Mohler, 1993; Blanco-Caqui et al., 2011). Cover crops have indeed proven to bring a beneficial effect on SOM and C content belowground (Battany and Grismer, 2000; Jackson, 2000; Steenwerth and Belina, 2008; Messiga, et al., 2015), countering the negative effects of monocultures on these soil traits.

Furthermore, when opting for the use of cover crops in replacement of herbicide applications for weed control, there is the obvious consequence of a reduction in chemical inputs to the soil protecting land's quality as well as the environment (Jeuffrov et al., 2002; Tourte et al., 2008).

2.2.3. Enhancement of Soil Organic Matter and Nutrient Contents

The content of SOM is a major contributor to soil health. Among the main responsible for increasing SOM are heterotrophic microorganisms, which decompose dead plants into organic matter rising soil carbon content (Havlin et al., 1990), and plant communities, which increase C-based compounds present in the soil through their root exudations. Soil organic matter content has a major influence on nutrient content underground and water holding capacity (Morlat and Jacquet, 2003), Moreover, it has a big impact on soil microbial populations and soil processes, as well as on water retention capacity (Baldock and Nelson, 2000).

Common cultivation practices, such as tillage, have been associated with a loss of SOM (Six et al., 1999), therefore, cover cropping and no-till techniques have become the most common techniques for preventing SOM loss (Steenwerth and Belina, 2008). Indeed, many studies have shown data on the influence of cover crops' presence on improving SOM (Blanco-Canqui et al., 2011; Nascente et al., 2013; Soti et al., 2016; Chou and Vanden Heuel, 2018) and additional biomass C inputs (Blanco-Canqui, 2013; Poeplau and Don, 2015). In fact, cover crops contribute to C sequestration and C cycling through

the ecosystem, thereby promoting a better soil structure, water holding capacity, and an enhanced cation exchanged capacity. Obi (1999) reported enhancements by 28% SOM with the presence of grass cover crops in Nigerian soils; and previously, Welker and Glenn (1988) obtained similar results when they studied the differences in soils with tilling technique or the use of herbicide application contrasting to a no-tilled soil. Regarding viticulture, Steenwerth and Belina (2008) used cover crops from the Poaceae family (Merced rye - *Secale cereale* - and Trios 102 - *Triticale x Triosecale*) to compare SOM content in a cover cropped lands and in a bare soil. Results showed an enhancement in SOM content and CO_2 efflux. Cover crops have a large influence in soil fertility, as they can improve nutrient cycling and availability, especially N if leguminous species are planted (Doran, 1980; Vyn et al., 2000; Parking et al., 2006; Bergkvist et al., 2011; Ferrara et al., 2021), and prevent leaching (Tonitto et al., 2006; Kasper and Singer, 2011; Quemada et al., 2013). In addition, a greater soil exploration by the root system enhances nutrient circulation and contributes for a more efficient usage (Lynch, 2007). Furthermore, cover crops represent an efficient nutrient storage at a long-term level under certain climatic conditions, crop residue additions from cover crops may promote soil organic C and N accretion as well as increase the availability of P, K, Ca, Fe, and Mg in some soil types (Managing Cover Crops Benefits, 2007). For instance, Fleishman et al. (2021) planted red fescue (*Festuca rubra,* Poaceae family) in the under-vine spaces in a vineyard of Pennsylvania State and evaluated C and N contents in the soil profile. They found enhancements in soil C content by 56% and 44% at soil depths of 1-20cm and 21-40 cm, respectively; and increases in soil N content of 37% and 19% at the same soil depts, respectively. They attributed these increased to the under-vine cover crops' root biomass.

2.2.4. Improved Soil Microbial Diversity and Abundance

Broadly, plants absorb most nutrients in their inorganic form, whilst in general, microorganisms can take any organic or mineral form (Lavelle et al., 2005). Hence, their action in the soil is crucial, both for the environment and for plants, since the microbial activity regulates the course of elements (Perry, 1995) and adjusts plant demand (Lavelle et al., 2005). Thus, soil microbial communities are key components of the soil due to their essential roles, but they are particularly sensitive to external to environmental alterations when compared to soil chemical and physiological properties (Yao et al., 2013).

As a result of the cover crops' presence, SOM content and nutrient circulation increase, and consequently microbiological activity is also enhanced (Kim et al., 2020). Data on improved microbial biomass, bacterial richness and microbial enzymatic activity proved that cover crops indeed support microbial activity and needs. In particular, legumes have proven to supply microbial nutrient needs

due to their fast decomposition (Faria et al., 2004; McGourty and Reganold, 2005; Li et al., 2012; Surucu et al., 2014; King and Hofmockel, 2017)

Kim et al. (2020) conducted a meta-analysis, comprising different soil types from different studies, to compare soil microbiome within cover cropped soils and bare soils, and results showed an increase in microbial abundance by 27%, in microbial activity by 22%, and in microbial diversity by 2.5%. In vineyards, Quecedo et al. (2012) found that permanent grass cover (mix of tall fescue and ryegrass, belonging to the Poaceae family) improved soil physical and biological properties, compared to the bare soil, and the green cover specifically enhanced microbial biomass and enzymatic activity. Furthermore, in the study of Chou and Vanden Heuel (2018), tall Festuca (Poaceae family) showed to effectively improve microbial activity by its contribution to labile C enrichment in the soil.

The presence of cover crops induces an enhancement of symbiotic associations as well, namely with AMF, especially by an increased root area for colonization and sporulation (Soti et al., 2016) and by creating more suitable soil environment to attract mutualistic microorganisms (Cheng and Baumgartner, 2010; Kim et al., 2020; Arruda et al., 2021), Therefore, use of cover crops represents a natural and sustainable tool to proliferate mycorrhizal population (Kabir and Koide, 2000; Brito et al., 2013; Soti et al., 2016; Brígido et al., 2017),

Table 1 – *Ecosystem Serviced Provided by Cover Crops in Vineyards.*

Benefits	Cover crop specie	Observations	Location	Reference
Reduce Soil Erosion and runoff	Fabaceae family: *Vicia faba; Vicia sativa; Trifolium subterraneum;* Poaceae family: *Festuca rubra; Lolium perenne; Triticum durum; Festuca ovina*	Different treatments were studied, showing different combinations of cover crops and comparing them to conventional tillage. Conclusions suggested that planting appropriate cover crops will increase results.	Sicily, Italy Mediterranean Vineyard	Novara et al. (2011)
Improved soil organic matter, C dynamics, and microbial activity	Poaceae family: Trios 102 (Triticale _ Triosecale) and Merced Rye (Secale cereale L.)	Trios 102 had better results on increasing C in the soil, yet less biomass than Rye.	California, USA Mediterranean climate	Steenwerth and Belina (2008)
Improvements on soil aggregate stability, microbial respiration rate, and carbon mineralization. Vine vegetative growth	Under-vine cover crops of: Fabaceae family: alfalfa Poaceae family: tall fescue Asteraceae family: chicory Brassicaceae family: tillage radish	Inconsistency on cover crop' effects. Under-vine chicory showed to reduce pruning weight and fruiting zone canopy, but the other cover crops had no impact on vine vegetative growth. Tall fescue improved microbial respiration rate and mineralization.	New York, USA	Chou and Vanden Heuel (2008)
Soil aggregation and strength Grapevine root growth	Poaceae family: ryegrass and wheat straw	Ryegrass had better results compared to wheat straw	Victoria, Australia	Wheaton et al. (2008)
Soil stability	Poaceae family: ryegrass (*Lolium multiflorum Lam*.)	Aggregate stability	British Columbia, Canada	Hermawan and Bomke (1997)
Improved soil microbial communities	Fabaceae family: *Medicago polymorpha* Poaceae family: *Avena sp., Cynodon dactylon, Hordeum murinum* Geraniaceae family: *Erodium chium*	Covered soil presented duplicated number of pores of AMF	University of the Balearic Islands, Spain	Capó-Bauçà et al. (2019)
Herbicide suppression	Fabaceae family: strawberry clover (*Trifolium fragiferum*)	**Under-vine cover crop** This study has observed increased water stress, although yield and berry quality were not affected	Navarra, Spain	Abad et al. 2020

2.3. Cover Crops' Benefits To Grapevine

Beyond cover crops' benefits to the environment, the practice may bring great advantages to the main crop (table 2). First and foremost, with the correct knowledge and ideal implementation, the main crop will profit from better soil fertility, improved water infiltration rates, soil organic matter, and soil aggregation that commonly derive from the cover crops. In addition, other direct beneficial effects can be observed at the grapevine level, such as greater vigour control (Tasic et al., 2007; Hatch et al., 2011), and an enhancement in canopy condition, i.e., less dense canopy causing greater berry environment (more direct light exposure and higher temperatures) (Monteiro and Lopes, 2007; Tasic et al., 2007; Lopes et al., 2008). An improvement in berry and wine quality, as well as a reduction in disease risk, may be also observed (Morlat and Jacquet, 2003; Nazrala, 2008). In addition, cover crops are habitats to beneficial organisms, that act as biological pest control (Sullivan, 2003) (Table 2).

2.3.1. Vigour Control

There are many humid grapevine growing regions worldwide, for instance, mid-Atlantic US (Giese et al., 2014), which have fertile soils and plentiful rainfall, or even some Mediterranean climate regions, that can have abundant spring rainfall. In such cases, and also in vineyards with deep soils, vine vegetative growth rates can be excessive, creating unbalanced canopies (dense canopies, with higher temperatures and less light exposure) with unfavourable microclimates prone to diseases (Smart and Robinson, 1991; Valdés-Gómez et al., 2008; Austin et al., 2011). Large grapevine canopies represent indeed a challenge to grape-growers also due to their management costs and compromise fruit quality derived for suboptimal sunlight exposure (Smart, 1985; Smart and Robinson, 1991; Valdés-Gómez et al., 2008; Austin et al., 2011). In these cases, competition for water resources caused by cover crops may be advantageous, consequently reducing grapevine vegetative growth and vigour (Lopes et al., 2004, 2008; Tesic et al., 2007; Hatch et al., 2011). In addition, water use efficiency is improved in the main crop (Linares et al., 2007; Lopes et al., 2016). As a result of the more positive balance between vegetative and reproductive growth, berry composition, as well as must and wine quality (color and sensory notes) can be ameliorated (Ingels et al. 2005, Smith et al., 2008; Xi et al., 2011; Pérez-Álvarez et al., 2015). The improvements are related to a greater fruit zone microclimate and due to a reduction in berry size, allowing a greater skin/pulp ratio (Linares et al., 2007). Moreover, higher soluble sugar and total phenols (Spayd et al., 2002; Monteiro and Lopes, 2007; Xi et al., 2011; Perez-Alvares et al., 2015) and anthocyanin concentration (in red grapes), and even an increase in wine alcohol content (Geoffrion, 1999) can be observed. Hence, cover crops may enhance the value of grapes.

2.3.2. Biological Pest Control

Excessive grapevine vegetative growth leads to dense canopies, with less light exposure and more humid microclimates that nurture diseases (Smart and Robinson, 1991; Elmer and Michailides, 2007). Even in more dry regions, there is a need for extensive canopy management (shoot and leaf trimming) that requires effort and costs. In such contexts, the establishment of cover crops can be an advantage, because the decrease that they induce in grapevine's vegetative growth, may help reduce the risk of diseases that proliferate in humid canopy microclimates (Oidium, Botrytis, Mildew) (Morlat and Jacquet, 2003; Tesic et al., 2007). Furthermore, green covers provide shelter (Thomas et al., 1991; Landis et al., 2000; Frank and Shrewsbury, 2004; Frank et al., 2008; Sharley et al., 2008) and food (for example nectar and pollen) (Landis et al., 2000; Wäckers et al., 2005) to many beneficial living organisms that are antagonist of insect pests, nematodes, and pathogens. For example, several studies show that when introducing cover crops, natural pest enemies are increased (Hooks and Johnson, 2003; Irvin et al., 2006; Prasifka et al., 2006; Ponti et al., 2007). In the experiment of Begum et al. (2006), authors studied green covers based on selective food plants in a vineyard in New Zealand as biological grapevine insect pest control. The cover crops attracted advantageous insects and the results showed that flowering shoots improved pest predators' survival.

Due to the importance of cover crops for pest control, the correct choice of cover crop species is essential to meet farmers' goals (Snapp et al., 2005). As an example, Danne et al. (2010), while comparing endemic perennial cover crops (native cover) with introduced oats (*Avena sativa*), concluded that the first one had a greater potential to increase the population of beneficial invertebrates, yet also showed more incidence of potential pest species.

The better soil conditions created by cover crops can also promote mutualistic relationships between soil microorganisms and the main crop (with AMF, for instance), which can promote grapevine tolerance to a variety of biotic stresses (Kabir and Koide, 2000).

Therefore, before establishing cover crops in vineyards, several factors must be considered, such as the degree of competition with grapevines, their adaptation to the local environment, and their predisposition to harbor advantageous organisms to the grapevine (Giese et al., 2014). If these conditions are fulfilled, the benefits may be virtuous for both the environment and the main crop.

Table 2: *Observed benefits of cover crops to grapevine and wine in different studies*

Benefits	Cover crop specie	Observations	Location	Reference
Controlled vigour (limit grapevine vegetative growth) and enhanced berry and wine quality	Poaceae family: grass	The reduction in vegetative growth improved grape composition by lowering titratable acidity and increasing total phenols and anthocyanins in the berry skin. These changes were noticed in wine as well, increasing the value.	Alenquer, Estremadura, Portugal	Lopes et al. (2008)
Controlled vigour (limit grapevine vegetative growth)	Poaceae family: tall fescue (Festuca arundinacea Shreb.) 'KY-31' and 'Elite II', hard fescue (*Festuca ovin*a L.) 'AuroraGold', perennial ryegrass (*Lolium perenne* L.), orchardgrass (*Dactylis glomerata* L.),	Elite II fescue was evaluated as the optimal cover crop due to its establishment and growth characteristics, inhibition of vine vegetative development, and low influence on crop productivity.	Western North Carolina, USA	Giese et al. (2014)
Controlled vigour (limit grapevine vegetative growth)	Poaceae family: Winter rye (Secale cereale L.)	A Decreased Vigour was observed in plots with rye cover crops, which led to increase incidence on berry sunburn	Lisbon, Portugal	Nogales et al. (2021)
Vegetative vigour reduction and slight grape quality increasement	Perennial grass and legume mixture	Yield reduction and slight quality improvements	Central Majorca, Spain	Pou et al. (2011)
Higher water use and vegetative growth reduction. reduced must acidity and increased berry skin total phenols and anthocyanins.	permanent resident vegetation, and permanent sown cover crop (grasses, 60%, and legumes, 40%, mixture) Poaceae family: (Grasses) *Lolium perenne* L. 'Nui', L. *multiflorum* Lam. 'Bartı′ssimo', *Festuca ovina* L. 'Ridu', F. *rubra* ssp. *rubra* 'Echo') Fabaceae family: (legumes) *Trifolium incarnatum* L. 'Red', T. *repens* L. 'Huie' and T. *subterraneum* L. 'Claire'	The cover crop treatment did not influence grapevine yield or berry sugar accumulation	Alenquer, Estremadura, Portugal	Monteiro and Lopes (2007)
Improved aroma compounds concentration in berry and wine	Fabaceae family: clover, alfalfa, and tall fescue	The best results were observed with the alfalfa cover crop species, marking the highest value, followed by tall fescue treatment.	Shaanxi Province, China	Xi et al. (2011)
Higher anthocyanin concentration	Poaceae family: ryegrass Fabaceae family: Subterranean clover Native cover	Ryegrass effects on compounds concentration were more effective in the first year of the study, while in the second year, the native cover had the best results. Clover had lower concentrations than the other treatments.	Leiro, Ourense, NW Spain	Bouzas-Cid et al. (2016)

Table 2: *Observed benefits of cover crops to grapevine and wine in different studies*

Benefits	Cover crop specie	Observations	Location	Reference
Improved must quality due to reduced yield. reduced pest development	<u>Fabaceae family</u>: legume mixture <u>Poaceae family</u>: grass mixture	The grass mixture increased the content of sugar, anthocyanins, and polyphenols, whereas legume mixture and natural covering reduced total polyphenols and anthocyanin content, respectively."	Sardinia, Italy	Muscas e al. (2017)
Biological control and weed suppress under-vine (avoidance of herbicide)	<u>Brassicaceae family</u>: Alyssum (*Lobularia maritima* L.) and mustard (*Brassica juncea*) <u>Boraginaceae family</u>: borage (*Borago officinalis* L.) <u>Polygonaceae family</u>: buckwheat (*Fagopyrum esculentum* Moench) <u>Apiaceae family</u>: coriander (*Coriandrum sativum* L.)	Greenhouse experiment of ground-cover plant species that improved performance of the egg parasitoid *Trichogramma carverae* to control the leafroller pest *Epiphyas postvittana.*	Australia and New Zeeland	Begum et al. (2006)
Help controlling diseases	<u>Fabaceae family</u>: legume mixture <u>Poaceae family</u>: grass mixture	The study aimed to understand the effect of cover crops on the development of *Plasmopara viticola* and *Erysiphe necator* by analyzing favourable microclimate. Tilled soil showed higher infection percentage. But there was a variation on the disease control according to the cover crop type and disease.	Northwest Sardinia, Italy	Fernandes de Oliveira et al. (2021)

2.4. Inter-Row versus Under-Vine Cover Crops

Many vineyards around the world use cover crops in the inter-row as a soil management strategy because, in many cases, the benefits outweigh any potential drawbacks (Steenwerth and Guerra, 2012). However, in Mediterranean climates, the area under the vines (i.e., in the vine rows) is frequently kept free of vegetation to minimize competition with the main crop, both for nutritional and water resources.

Mechanical tillage or herbicides are typically used to maintain a bare under-vine region. However, there is an urge to reduce or eliminate the use of chemicals in agricultural soils, which compromises soil and environmental health, as well as to avoid tillage that expedites soil erosion (Shrestha et al., 2013). Given the disadvantages of employing herbicides or mechanical tillage to manage the under-vine soil, the planting of low-competition cover crops looks to be a viable alternative (Jordan et al., 2016; Karl et al., 2016). This hypothesis has only been tested in a small number of studies (Hickey et al., 2016; Jordan et al., 2016; Karl et al., 2016; Chou and Vanden Heuvel, 2018; Coniberti et al., 2018; Penfold et al., 2018), and almost none of them have been undertaken in Mediterranean regions.

In the study of Chou and Vanden Heuel (2018), where under-vine cover crops were established in a vigourous and mature vineyard located in a cool climate, showed that under-vine planted chicory had the ability to reduce vine vegetative growth without reducing yield, which was one of the objectives, and other parameters were benefited, such as soil aggregation microbial respiration rate, and carbon mineralization.

3. Arbuscular Mycorrhizal Fungi

The term mycorrhiza was first used in 1885 to describe the symbiosis between biotrophic fungi and land plant roots and is composed of the Greek words for fungus, *mycos*, and *rhiza* which means root (Garg and Chandel, 2010). On account of morphology, there are three predominant kinds of mycorrhizae: endomycorrhiza, which colonizes root cortical cells; ectomycorrhiza, which does not penetrate root cells but spreads apoplastically; and ectendomycorrhiza, with intermediate characteristics (Varma, 2008). Endomycorrhizae are further separated into categories considering diverse morphological and anatomical characteristics: orchid mycorrhiza, ericaceous mycorrhiza, arbutoid mycorrhiza, monotropoid mycorrhiza and, arbuscular mycorrhiza (Brundrett, 2004; Moore et al., 2020).

Arbuscular mycorrhizal fungi are the most common group of mycorrhizal fungi, with distinctive morphological characteristics, that belong to the monophyletic phylum Glomeromycota. Arbuscular mycorrhizal fungi are found in roots of more than 80% of terrestrial plants comprising 92% of plant families, and they are probably present in almost 90% of land plants' rhizosphere (Qiu, 2006; Wang and Qiu, 2006; Helgason and Fitter, 2009; Kivlin et al., 2011).

Arbuscular mycorrhizal fungi have been fundamental partners for many *Plantae* populations (St. John and Coleman, 1982; Trouvelot et al., 2015), since 460 million years ago, date of the earliest spores and hyphae from Glomeromycetes fossils (Redecker et al., 2000). In fact, this relationship seems to have been crucial in the evolution of land plants, which needed the assistance of AMF to obtain essential nutrients for their development (Selosse and Le Tacon, 1998), as demonstrated by the fact that the first land plant fossils showed AMF colonization (Remy et al., 1995).

These fungi have received a vast number of taxon names since scientists started to study them. Furthermore, there have been several modifications on their classification. However, it is accepted now that Glomeromycota, within the fungi kingdom, have four different orders, according to Redecker et al. (2013): *Glomerales, Diversisporales, Paraglomerales* and *Archaeosporales*. Agricultural soils are mostly dominated by AMF from the Glomerales order, where species like *Rhizoglomus irregulare, Funneliformis mosseae, F. geosporum* commonly appear (Schreiner and Mihara, 2009; Balestrini et al., 2010; Lumini et al., 2010). As obligate symbionts, AMF feed on photosynthetically fixed C from the host, on whom they entirely depend (Bago et al., 2000), in exchange of minerals absorbed by extraradical hyphae (Smith and Read, 2008). As the fungus depends on the plant for carbon, this enters great exchanges with the plant for the absorbed nutrients, providing the host with large amounts of compounds (Schreiner et al., 2005).

Arbuscular mycorrhizae are differentiated from the other fungal phyla by their unique structures. The fungus reproduces asexually by chlamydospores that germinate in the rhizosphere. Then, a signal exchange between both partners (fungus and plant) happens: whilst the germinating spores release oligosaccharides (chitooligosaccharides) and lipooligosaccharides (Gutjahr and Parniske, 2013), the host liberates fungal-signaling molecules, strigolactones, plant hormones, that likely improve mutual recognition in the pre-symbiotic stage (Kosuta et al., 2003; Kuhn et al., 2010). These hormones are germination stimulants and induce hyphal growth (Giovannetti and Sbrana, 2001; Akiyama et al., 2005). The germinating spores develop germinating tubes that grow and differentiate into hyphae that continue growing until reaching the host. In turn, when the hyphae contact the root´s surface, differentiate to create a pre-penetration apparatus (PPA)-hyphodium (Genre et al., 2005). Then, the fungal hyphae colonize the root inner cortex and spread apoplasticly (Gutjahr and Parniske, 2013). Next, AMF penetrate into cortical cells and forms some highly branched structures within called arbuscules (Genre et al., 2008; Harrison, 2012), without compromising plant cells integrity (Harrison,

1997). These formations are the key of the symbiosis –where the exchange of nutrients and water between the AMF and the plant happens (Schübler et al., 2001; Smith and Read, 2008; Gutjahr and Parniske, 2013). Therefore, AMF are composed by the extraradical mycelium (ERM) spores; intraradical hyphae that form the intraradical mycelium (IRM), arbuscules and vesicles (Varma, 2008) (Figure 5). Although in most plants AMF produce arbuscules, in some cases, intraradical coils can be formed instead (Dickson, 2004).

Once mineral nutrients are absorbed, readily they enter in an exchange medium, that can happen in small quantities intercellular (Ryan et al., 2003), but mainly in the extended arbuscules present in the root cells (Bago et al., 2000), that are treelike forming a vast surface area connecting plant and AMF.
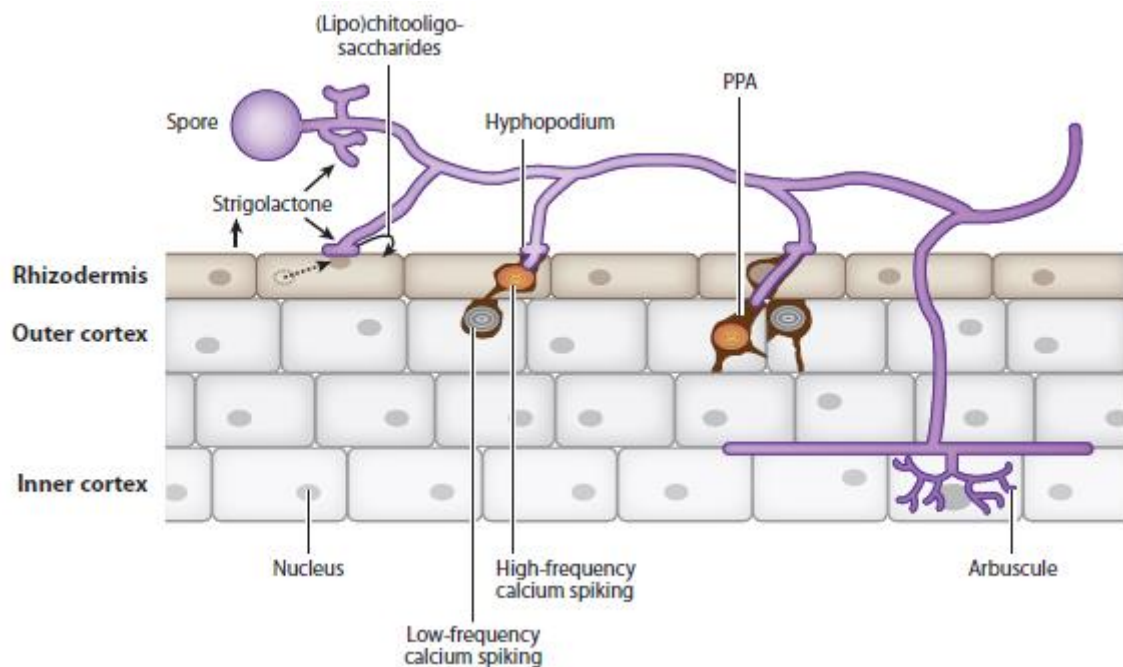
Figure 5 - Diagrammatic representation of AMF progression into plant root. **Source**: Gutjahr and *Parniske*, 2013.

These soil-born microorganisms are obligate biotrophs, and therefore, they depend on their hosts to function and survive, with whom they exchange mutual benefits (Schübler et al., 2001). During their development, the micro-symbionts grow outside the roots and generate extraradical hyphae (Cavagnaro et al., 2005; Varma, 2008), that create an ample system of fine and effective filaments that will cover greater soil area than the plant root system (Figure 6). The fungal hyphae can cover considerably more than 50% of field area (Schreiner and Linderman, 2005), constituting a great part of soil biomass (Leake et al., 2004). Through this scheme, the AMF provide the plants with water and mineral nutrients in exchange for plant-assimilated carbon in the form of photosynthetic products and

lipids (St. John and Coleman, 1982; Bago et al., 2000; Smith and Read, 2008; Varma, 2008; Franken, 2010; Smith and Smith, 2011).

Figure 6 – Contribution of AMF in root network system (right), comparison of non-mycorrhizal root (left).
Source: Kapoor et al., 2013

In grapevines, the symbiotic relationship gives better balanced growth, reduces plant mortality after transplant or replant, and can increase effective substances such as minerals, phenolic and aroma compounds (Harrison and Richardson, 1994; Cavagnaro et al., 2005; Torres et al., 2018a), which in turn can lead to a higher yield and berry quality. Furthermore, 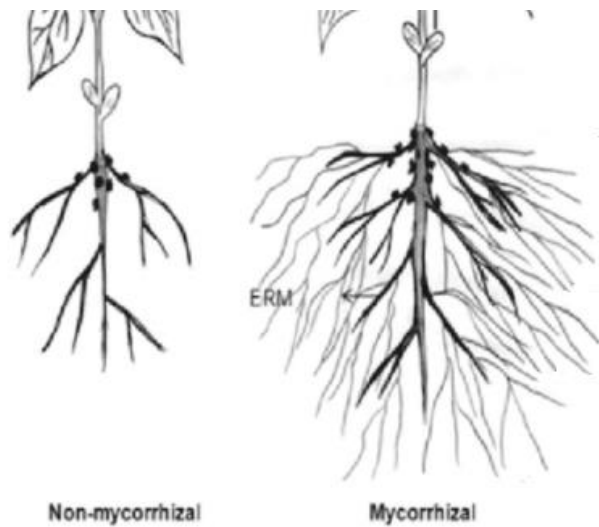AMF improves soil structure, stability, and aggregation (Cavagnaro, et al., 2005; Bedini, et al., 2009) as well as soil quality due to their beneficial effect on other soil microbial populations that are involved in nutrient cycling (Smith and Read, 2008; Varma, 2008), which is one of the major ecosystem's services that has been suffering from human's exploration of land. Additionally, AMF promote water infiltration and retention, therefore reducing the risk of erosion (Rilling and Mummey, 2006; Smith and Read, 2008; Trouvelot et al., 2015). For a finer perception of AMF effects in grapevine, Table 3 resumes the effects observed in different studies.

The symbiotic relationship has a great impact on the plant, and it is considered essential many times (Jeffries et al., 2003; Barrios, 2007). The knowledge about these fungi is not yet major, but it has been an object of study in the last decades. They are increasingly considered an essential tool in sustainable agriculture, not only for their capacity to act as a biofertilizers, biofortifiers or even biopesticides, due to their capacity to reduce the use of chemicals, but also for all the advantages that they offer to the ecosystem (Jakobsen, 1995; Ortas, 2012).

3.1. Benefits of Arbuscular Mycorrhizal Fungi Symbiosis for Plants

3.1.1. Enhancement of Plant Growth and Nutrition Status

Agriculture has been sustained with the help of chemical fertilizers in order to fulfil the great food demand of an increasing world population. But these carry a huge burden of consequences for the environment, wearing down our land, polluting the soil and water along them. Thus, agroecosystems are exposed to an enormous quantity of chemicals, pesticides and herbicides. The application of fertilizers to compensate for nutrient deficiency, especially P, is highly needed in many fields, specifically, in acidic soils, loaded in cations that readily sequester the inorganic phosphate (Sawers et al., 2008) or in high rainfall areas. However, these applications may compromise soil biota and soil properties, consequently degrading the soil (Rose et al., 2016). In this context, microbial fertilizers are earning significance as a sustainable alternative to chemical fertilizers (Alori et al., 2017).

"Biofertilizer" has become a popular term in recent years (Igiehon and Babalola, 2017). Scientists use it to describe microbial isolates with the potential to enhance plant growth and development (Alori et al., 2017) or a combination of organisms, that occur naturally in the ecosystem, that is used to promote soil fertility (Begum et al., 2019). Among them, AMF are sold today to replace in part inorganic fertilizers, and in fact, is believed that the correct use and management of AMF can reduce the use of chemical fertilizers to 50% (Begum et al., 2019).

The contribution of AMF to plant mineral uptake is primarily due to the greater soil exploration, and in fact, mycorrhizal roots are more efficient in nutrient absorption than the non-mycorrhizal ones (Smith and Read, 2008). The AMF extraradical mycelium extends out of the roots into the soil and go further the nutrient depletion zone (Smith and Read, 2008). Then hyphae produce branched absorbing structures (BAS) that are thinner hyphal branches, compared to grapevine root hair (Marschner and Dell, 1994; Smith and Read, 2008), whose function is nutrient absorption (Bago et al., 1996). The network created is able to reach zones that are inaccessible for plant roots themselves (Marschner and Dell, 1994; Smith and Read, 2008). Furthermore, during symbiosis, fungal and plant genes that encode nutrient transporters and catabolic enzymes are positively regulated (Bajpai et al., 2019), for example P transporters (Bucher, 2007; Javot et al., 2007, Smith and Smith, 2011). This results in improved nutrient uptake and water, and consequently plant growth (Bowles et al., 2016). For instance, AMF can take up to 80% of total N and P needs to the plant (Douds and Johnson, 2007; Van Der Heijden et al., 2015)

In fact, one of the most important nutrients absorbed by AMF is P, because they are highly efficient on the uptake of this element (Javot et al., 2007). Phosphorus is essential for plant growth and development. After N, this nutrient is the most plant growth limiter (Menge et al., 1978; Bucher, 2007; Balzergue et al., 2010), and it is taken up by plants at its inorganic form (P_i) HPO_4^{2-} (Karandashov and Bucher, 2005; Fellbaum et al., 2012). This form is the only one available to plants due to the low P mobility in the soil (Sawers et al., 2008), and it is rapidly consumed in the region surrounding plants

roots, creating a depletion zone (Bucher, 2007). Organic P (P_o), on the other hand, represents 20-80% of the total soil P content (Shen et al., 2011).

Phosphorus mobilization by AMF may involve both P_i (Smith and Read, 2008) and P_o forms (Andrino et al., 2021). Phosphate solubilizing microbes (PSMs) are beneficial bacteria that can hydrolyze inorganic insoluble phosphorus compounds into soluble P that plants may easily absorb (Kalayu, 2019). However, AMF can also mobilize organic P, but to a lesser level and in a less effective manner since it supposes high C costs for the fungal partner. They do this by synthetizing acid phosphatases: AMF can secrete their own acid phosphomonoesterase in order to mineralize organic P forms and gain access to P sources that non-mycorrhizal plants cannot reach (Sato et al., 2015). As soon as P is absorbed by the AMF, it is quickly accumulated in the fungus's vacuoles (Solaiman et al., 1999) and converted into polyphosphate (Poly-P) a polymer that facilitates storage (Kornberg et al., 1999). This form can be more easily transferred from extraradical hyphae to the intraradical ones (Smith and Read, 2008; Uetake et al., 2002). Then, the Poly-P hydrolyses release Pi within the root cells (Javot et al., 2007).

Nitrogen is also an essential nutrient for plants, and the most abundant mineral element within plant tissues, whose absence compromises plant growth (Botton and Chalot, 1995). Nitrogen uptake is also of great importance in mycorrhizal symbioses. Arbuscular mycorrhizal fungi are able to absorb different forms of N (NO_3^-, NH_4^+ and organic N) and their extraradical hyphae are extremely effective at acquiring and transporting inorganic nitrogen to host plants. (Hodge et al., 2001; He et al., 2003; Govindarajulu et al., 2005). A preference for NH_4^+ compared to NO_3^- has been reported (Johansen et al., 1992; Johansen et al., 1996; Toussaint et al., 2004; Gachomo et al., 2009). Moreover, AMF can also transfer N from one plant to another one through the ERM that can connect them (He et al., 2003).

Although most studies regarding the influence of mycorrhizal symbiosis on plant nutrition have been focused on P and N, some other studies also show an increase in the content of magnesium (Mn), boron (B); zinc (Zn), copper (Cu), and even iron (Fe) and sulfur (S) between inoculated and non-inoculated plants (Johansen et al., 1992; Clark and Zeto, 2000; Cavagnaro et al., 2006; Smith and Read, 2008; Carbonnel and Gutjahr, 2014; Nicolás et al., 2015; Igiehon and Babalola, 2017), enhancing the accessibility as well as their transference to the host (Rouphael et al., 2015). For example, Zn, is essential for chloroplast configuration and leaf growth, and its lack of availability is a common problem (Hacisalihoglu and Kochian, 2003). Kochian (2000) reported that around 30 % of world's soil suffer from Zn deficiency. With the help of AMF, Zn uptake is substantially enhanced (Cavagnaro, 2008; Ozdemir et al., 2010), and the same applies to Mg, mineral supplement that has significant effects on photosynthesis, enzyme activity, and ATP generation in the plant (Cakmak et al., 1994; Hermans et al., 2005; Cakmak, 2013).

Due to the improved nutrient uptake and increased hydraulic conductance at the root system of the plant, as well as an enhancement of the photosynthetic capacity in the leaves (Sanchéz-Blanco et al., 2004), a stimulated plant growth, vigour, and development can be observed in mycorrhizal plants (Birhane et al., 2012), which consequently lead to a greater plant biomass production (Chen et al., 2019).

In grapevines, AMF have also demonstrated to improve nutrient and water acquisition, and in fact, they rely on them for their normal growth and development (Hare Krishna et al., 2005, 2006; Trouvelot et al., 2015). These fungi can be especially relevant when vineyards are located in poor and dry soils, as it is the case for many Mediterranean vineyards. Although most studies are focused on N and P, some studies also point to the mycorrhizal improvement of other nutrient uptake in grapevines. For example, Schreiner (2007) studied the effects of AMF on 'Pinot noir' growth and nutrient uptake in two soils with varying of levels, and that AMF promoted Cu and S uptake. Also, Nicolás et al. (2015) showed that inoculated AMF species (*Glomus iranicum* var. *tenuihypharum* sp. *nova*) increased P, Ca and K in a vineyard in South-Eastern Spain.

3.1.2. Increased Tolerance to Abiotic Stress

Abiotic stresses – drought, salinity, mineral depletion, heat, heavy metals – represent a huge concern in agriculture (Latef et al., 2016) and are often the cause of great production losses, up to 70%, due to the severe impact they cause in plant growth, development, and health (Kumar et al., 2013). Grapevines are not an exception, and stress induced by drought, salinity and heavy metals are serious issues worldwide (Trouvelot et al., 2015). To face abiotic stress, plants need to modify their structure and morphology or adopt alternative strategies to limit stress damages (Latef et al., 2016). In this context, the symbiotic relationship with AMF has been proven to be an effective practice to enhance abiotic stress tolerance in grapevines and other cultures (Trouvelot et al., 2015; Popescu, 2016).

A substantial concern in agriculture is water availability, and climate forecasts point towards an increasing scarcity, mainly in dry regions like in Mediterranean climates, that will tend to become progressively arid in the next decades due to climate change (Schultz and Stoll, 2010). However, drought stress can also be a problem in soils with small electrostatic interactions, like coarse-textured and sandy soils, that have low water retention capacity and dry rapidly (Lovisolo et al., 2016).

Grapevine faces seasonal drought periods (Chifre et al., 2005; Chaves et al., 2010) and can resist to moderate water stress at different degrees depending on the *Vitis vinifera* cultivars and rootstocks (Zhang et al., 2016). Indeed, most grapevines are grafted into different rootstock varieties and hybrids that have distinct drought stress tolerance. For instance, rootstocks of *V. berlandieri x V. rupestris* hybrids are more drought tolerant than *V. berlandieri x V. riparia* hybrids (Tramontini et al.,

2013). Nevertheless, when they experience drought stress that induces water deficit in plant tissues, osmotic pressure is altered, and photosynthesis and metabolic processes are compromised leading to an important reduction in crop performance (Lovisolo et al., 2016), and ultimately to a growth restriction and development in vines (Fernandes-Silva et al., 2010). It is crucial then to find strategies to overcome this issue and to prevent farmers to spend huge amounts of water in irrigation.

It has been well demonstrated that AMF relieve water stress in grapevines and in many other crops (Schreiner et al., 1997; Augé, 2001, 2004; Augé et al., 2001, 2015; Ruiz-Lozano et al., 2015; Torres et al., 2021a) by improving water use efficiency (Valentine et al., 2006). The main is the greatest soil exploration the of the ERM of the AMF in search for water (Gutjahr and Paskowski, 2013). Besides, the symbiosis between AMF and plant has shown to influence important physiological processes within the plant, such as the regulation of abscisic acid (ABA) metabolism that controls stomatal closure (Augé, 2001, 2004; Jezek and Blatt, 2017). Arbuscular mycorrhizal fungi promote higher osmotic adjustment (Kubikova et al., 2001) and transpiration rates (Morte et al., 2000). These factors enhance water stress tolerance on their hosts, as well as heat tolerance, due to the evaporative cooling promoted in leaves by higher transpiration rates (Urban et al., 2017).

Common abiotic stresses found in vineyards are salinity, metal and pollutant accumulation in soils. Grapevine is sensitive to salt stress (Walker et al., 2002; Shani and Ben-Gal, 2005) which generates osmotic stress, limitation in transpiration and photosynthesis (Shannon and Grieve, 1998), which causes cells to lose their turgor due to a decrease in chemical activity (Serrano et al., 1999). Salinity decreases the root's water potential, resulting in slower growth and a set of metabolic alterations comparable to those seen under water stress (Munns, 2002). Some AMF isolates are adapted to or capable of developing in saline environments (Gárcia and Mendoza, 2007). The fungi can alleviate salinity stress, both in grapevines and in many other crops studied (Trouvelot et al., 2015) by increasing nutrient uptake in saline/salinized soils, especially P (Giri et al., 2003; Giri and Mukerji, 2004), by enhancing photosynthesis (Sheng et al., 2011), and by sustaining growth under such circumstances. In grapevines, improved vegetative growth and yield have been documented under salinity conditions due to AMF inoculation (Belew et al., 2010; Khalil, 2013; Begum et al., 2019).

Besides salinity, AMF are also capable of reducing metal toxicity in their hosts (Rivera-Becerril et al., 2002; Lopez-Millan et al., 2009). For instance, Cu, an essential functional component for multiple organisms, when accumulated in excess in the soil, it can be toxic for them. However, AMF evolved mechanisms to overcome this toxicity and can colonize roots and survive under these conditions (Ferrol et al., 2009, 2016). Furthermore, the symbiosis reduces the impact of toxicity within the host, by improving nutrient supplies (Smith and Read, 2008), by reducing oxidative damage, as well as by decreasing Cu bioavailability in contaminated soils (Ferrol et al., 2009). In the case of grapevines,

several studies demonstrate an improvement in plant tolerance to this element toxicity (Nogales et al., 2019, 2021, Brunetto et al., 2019; Agudelo et al., 2020; Victorino et al., 2021).

Concerning other contaminants such as Zn (Castiglione et al., 2007; Tiecher et al., 2016) and Pb (Yang et al., 2015a), AMF can also immobilize them in fungal hyphae and spores (Ouziad et al., 2005; Punamiya et al., 2010, Begum et al., 2019). Furthermore, AMF are considered a biotechnological tool by virtue of their phytostabilization capacity and tolerance to heavy metals polluted soil (Yang et al., 2015a,b).

3.1.3. Protection Against Biotic Stress

Pathogens, pests, and root nematodes are a big issue in agriculture and viticulture. These agents are the cause of serious diseases that compromise crop production and yield (Gianinazzi et al., 2010), being fungal diseases the most common infections in grapevines (Trouvelot et al., 2015; González-Caetano et al., 2019). Among these, downy mildew, caused by fungus-like, *Plasmapara viticola,* a biotrophic oomycete, was reported to be the most important disease, a widespread problem in grapevines worldwide (Bois et al., 2017). Another usual infection in vineyards causing big production losses is the grey mould caused by *Botrytis cinerea*. However, other diseases can also affect grapevines such as the white root rot caused by *Armillaria mellea* (Nogales et al., 2009a,b), the black foot disease caused by *Cylindrocarpon* spp. or trunk diseases. (Halleen et al., 2006; Holland et al., 2019).

Some of these pathogenic infections, especially the ones affecting the aerial part of grapevines, can be prevented, or cured by the application of fungicides. However, some of the chemical fungicides that are widely and frequently used can represent a big threat to the environment and human health. Thus, it is necessary to develop biocontrol or plant biofortification techniques to overcome both, the negative impact of plant diseases and the ecological consequences of pesticide application, which involve the use of beneficial fungi or bacteria (Berendsen et al., 2012)

There is evidence that AMF symbiosis enhances tolerance to fungal and bacterial pathogen and nematode infections with a beneficial impact on plant's health (Azcón-Aguilar and Barea, 1997; Whipps, 2004; Li et al., 2006; Smith et al. 2008; Nogales et al., 2009a,b; Bruisson et al., 2016). Several factors can contribute to this biotic stress tolerance increase (Facelli et al., 2009), such as an enhancement in plant nutrition status, which leads to a stronger structure and health in vegetative tissues, reducing the negative effects of pathogens (Calvet et al., 1995; Pozo et al., 2002; Nogales et al., 2009a; Cameron et al., 2013) or a competition for resources between AMF and pathogens in roots. Fungal hyphae are also often able to compensate nutrient and water uptake in roots that are damaged by the attack of these pathogens, and that frequently lose function. Crops' mineral composition, indeed, improved by the colonization, is beneficial to combat various diseases (Seeram 2008).

Furthermore, AMF can activate induced systemic resistance (ISR), in their hosts, which is conferred by beneficial soil microbes in their hosts, that provides certain tolerance against biotrophic pathogens (Paszkowski, 2006). This happens due to priming defence, a warning response stimulated by previous contact (i.e. when the AMF colonizes the root), that confers a faster reaction against a new infection (Jung et al., 2012). Despite the bioprotective features that AMF can provide to plants (Jung et al., 2012) this fungal association further brings alterations in the rhizosphere of the host plant, attracting beneficial microbial communities that can act as antagonists to plant pathogens (Berta et al., 2002; Barea et al., 2005; Artursson et al., 2006; Lendzemo et al., 2007).

3.1.4. Increased Yield and Berry Quality

Given the influence of global warming on berry quality attributes, it's worth rethinking the usage of some novel or old management approaches that can control sugar accumulation and/or postpone or balance berry ripening (Palliotti et al., 2014). Mycorrhizal symbiosis enhances several metabolic processes inside the plant, including the synthesis of secondary metabolites and bioactive compounds (Harrison and Dixon, 1994; Strack and Fester, 2006; Schliemann et al., 2008), such as phenolic compounds (Gianinazzi et al., 2010). These are directly related to organoleptic features (Conde et al., 2007). Mycorrhizal plants can accumulate higher levels of phenolic compounds than non-mycorrhizal plants, and this effect is even more noticeable when plants are irrigated insufficiently (Baslam and Goicoechea, 2012). In grapevines, under water stress, AMF can also lead to phenolic compound accumulation in leaves and berries (Eftekhari et al., 2012; Torres et al., 2015, 2016). In addition, mycorrhizal symbiosis can increase phytohormone (particularly ABA) production in their hosts under abiotic stress (Wang et al., 2017), which has been related to an increase in grape quality (Balint and Reynolds, 2013; Alonso et al., 2016) Nevertheless, in some other studies, AMF colonization did not influence berry quality. For example, Karagiannidis et al. (2007) revealed no differences in berry total acidity and soluble solids between mycorrhizal and non-mycorrhizal plants. In Nogales et al. (2021), in inoculated field-grown grapevines, must parameters were also not affected (brix degree, acidity, pH).

3.2. Arbuscular Mycorrhizal Fungi and Ecosystem Services

Arbuscular mycorrhizal fungi are vital to terrestrial plant, creating with them a lifelong relation with enormous benefits. Furthermore, AMF biological functioning is also greatly noticed in soil and ecosystem services, and the new sustainable agricultural practices have been focused on enhancing mycorrhizal colonization to regenerate the soils and the overall agroecological system. When AMF

populations are preserved and colonization is properly stimulated, entire habitats can profit from this symbiosis, including vineyards (Oehl, 2018). There are already many studies focused on the effect of AMF in ecosystem services.

3.2.1. Soil Stability and Ecosystem Funtion

Soil structure and stability are important elements for agriculture, since they are crucial factors for optimal plant's status, alter the root environment and rhizospheric microorganisms in various ways, and are fundamental to prevent soil erosion and degradation. These two factors are especially important in the case of the considerable number of vineyards that are located on hills, where the risk of erosion is more considerable (Trouvelot et al., 2015).

Arbuscular mycorrhizal fungi have been shown to improve soil aggregate stability and structure through several mechanisms. Since AMF extend out of the roots into the soil, creating a complex network that embodies a major portion of soil biomass (Leake et al., 2004), it greatly contributes to the improvement of the aggregation of soil's particles (Rillig and Mummey, 2006; Adams et al., 2011; Leifheit et al., 2014; Amendola et al., 2017). Besides, AMF produce and exudate Glomalin, a glycoprotein, that has revealed to have a positive impact on hydrophobicity, and that increases stability of microaggregates, which in turn influences soil C storage by restricting C decomposition losses in the soil (Rilling and Mummey, 2006; Rilling et al., 2006), and contribute to water retention and soil health (Kohler et al., 2006; Bedini et al., 2009).

3.2.2. Improvement in Soil Biological Status

Microbial communities are dynamic in the soil and are a major factor for a healthy soil ecosystem (Hector and Bagchi, 2007; Trouvelot et al., 2015), since they participate in the variety of agroecosystem services that contribute to soil fertility, involving the biogeochemical cycling of plant nutrients, mostly in the rhizosphere (Azcón-Aguilar and Barea, 2015). Previous research has found that soil microbial diversity differed significantly between vineyards with conventional and organic managed, with bacterial populations being heavily influenced by tillage (Likar et al., 2017). Indeed, the loss of microbial diversity in soils compromises important soil functions, such as biogeochemical cycling, soil structure and function of plant and animal comunities (Smith and Read, 2008; Köhl et al., 2016). Mycorrhizal activity in the belowground ecosystem improves its biological status by attracting beneficial microorganisms with important functions in nutrient cycling and plant health, and by increasing soil enzyme activity, which in turn is correlated with an increased SOM content (Kabir and Koide, 2000; Kuimei et al., 2012). In addition, AMF can also enhance nutrient cycling, C assimilation

and SOM content (Gianinazzi et al., 2010; Soti et al., 2016). Arbuscular mycorrhizal fungi help on mobilization of nutrients (Feng et al., 2003; Hodge and Fitter, 2010), influencing the properties of the rhizosphere at a chemical and biological level, thereby creating a favourable environment for the proliferation of other beneficial microorganisms (Jeffries et al., 2003; Azcón-Aguilar and Barea, 2015; Trouvelot et al., 2015).

Torres et al. (2021b) conducted an experiment on potted grapevines, comparing fungal and bacterial communities among AMF inoculation with non-inoculated grapevines. improved plant-microbe associations in vineyards due to inoculation. Results showed a positive relationship between vineyard-soil-living microbes increased as a result of AMF inoculation. In this case, *Proteobacteria* and *Actinobacteria* phyla were predominant under AMF inoculated grapevines, which are responsible for N, P and C rhizosphere metabolism and in organic matter decomposition (Green et al., 2004; Jenkins et al., 2009; Bona et al., 2019). Furthermore, it was already reported that microorganisms from *Actinobacteria* phyla may have a role in regulating grapevine pathogens (Andreolli et al., 2016; Álvarez-Pérez et al., 2017).

Table 3: Different effects of arbuscular mycorrhizal fungi application on *Vitis vinifera*

Benefits	AMF Species*		Observations	Reference
Enhancement on grapevine physiological growth parameters	*Glomus intraradices*	Field Inoculation	Increased plant shoot dry weight	Camprubí et al. (2008)
	Mixed inoculum with best results accomplished by *Acaulospora laevis*, *Glomus manihotis* and the commercial mixed inoculum	Field Inoculation	Increased photosynthetic rate and leaf area	Hare Krishna et al. (2006)
Improved nutritional grapevine status	*Glomus iranicum var. tenuihypharum* sp. nova	Field inoculation through drip irrigation	Improved nutrient uptake (P, K, and C) and mobilization of starch reserves in the apex throughout the winter, which may have aided root development.	Nicolás et al. (2014)
	Mixed inoculum	Pre-inoculation in nursery conditions	Enhancement of the production of several secondary compound and higher accumulation of N, P, Mg and Fe	Hare Krishna et al. (2005)
	Mixed inoculum with best results accomplished by *Acoulospora. laevis*, *G. manihotis* and the commercial mixed inoculum	Field Inoculation	Increased Zn and P concentration	Hare Krishna et al. (2006)
	Glomus mosseae, *Glomus intraradices*, and *Scutellospora calospora*	Native and field inoculated (comparation)	Improved P uptake *G. mosseae* (native and nonnative isolates) also improved Cu, Zn and S	Schreiner (2007)
Protection against abiotic stress	Mixed inoculum	Pre-inoculation in nursery conditions	Increased survival and tolerance against stresses. Mainly water stress due to enhancement of CO_2 assimilations, photosynthetic rates and higher plant water content	Hare Krishna et al. (2005)
	Glomus fasciculatum	Nursery inoculation	Improved salt toleration	Belew et al. (2010)
	Rhizophagus clarus	Field inoculation at transplantation	Improved tolerance to Cu contaminated soils	Agudelo et al. (2020)

*The species names are in accordance with the research of origin.

Table 3: Different effects of arbuscular mycorrhizal fungi application on *Vitis vinifera*

Benefits	AMF Species*	Observations	Reference
Increased tolerance to biotic stress	*Glomus intraradices*	Inoculation Enhanced tolerance to *Armillaria mellea*	Nogales et al. (2009)
Increased yield and berry quality	*Rhizophagus irregularis*	Plant Inoculation Enhanced tolerance to Downy mildew and grey mould	Bruisson et al. (2016)

*The species names are in accordance with the research of origin.

3.3.   Funtional Diversity of Arbuscular Mycorrhizal Fungi

Arbuscular mycorrhizal fungi are native in nearly every soil (Abbott and Robson, 1982; Öpik et al., 2006; Jansa et al., 2009), although the different populations can vary according to the different ecosystems. There are morphological and functional differences among distinct AMF families, species or even isolates, that can show adaptations according to the environments and hosts (Friese and Allen, 1991; Dodd et al., 2000; Munklovd et al., 2004; Avio et al., 2006; van de Heijden and Scheublin, 2007). For instance, the distinct AMF species differ on their nutritional strategies (e.g. on their aptitude to obtain C sources such as glucose and sucrose (Bajpai et al., 2017), as well as on their colonization methods (Hart and Reader, 2002; Klironomos and Hart, 2002). Besides, distinct AMF species promote different effects on host plant performance as well as on soil properties (Allen et al., 1995).

According to their colonization, development, reproduction and survival strategies, i.e., the way they manage their energy resources (Pianka, 1970; Begon et al., 1996; Hart et al., 2001; Hart, 2002; van der Heijden and Scheublin, 2007; Ijdo et al., 2010), AMF can be grouped into two categories of life-history strategies (LHS): K-strategists, which grow slow and invest their resources and energy in their own development and survival (Pianka, 1970; Begon et al., 1996), and r-strategists are fast colonizers and focus their resources essentially on growing very fast and on producing offspring in response to highly competitive environments (Ijdo et al., 2010). Thus, they respond well to environmental disturbance. For instance, many species from *Glomus* genus, among which *G. intraradices* (*Rhizoglomus intraradices*) are r-strategists, since they survive and develop well after soil disturbances (Douds et al., 1995; Dodd et al., 2000).

The described concept of colonization *versus* persistence abilities is a reflection of the functional diversity that can exist among AMF, which leads to different growth rates, root colonization capacity, longevity and competitiveness under different environments (Hart et al., 2001). Furthermore, based on these functional capacities, the benefits that AMF can provide to plants and soils will be heterogeneous, although the effects of AMF depend also on other factors, such as the host genotype (Klironomos, 2002; Fitter, 2004; Pandey et al., 2005; Yücel et al., 2009) and ecosystem conditions (Munkvold et al., 2004).

For example, Munklovd et al. (2004) studied 24 *Glomus* isolates to study their functional diversity. Authors reported that P reserves in the plant differed among isolates, and this was closely linked with mycelium growth. As a result, length-specific P absorption varied among species, but functional aspects like fungal growth pattern and plant growth stimulation required lower phylogenetic levels. Because of the high intraspecific diversity found for mycelium development and P uptake enhancement, AMF communities with minimal species diversity may nonetheless have significant functional heterogeneity. It is also a proof of functional diversity the fact that isolates of the

same AMF species show lead to different growth responses in their hosts (Camprubí et al., 2008). In that work, one commercially sold *G. intraradices* (now reclassified as *R. irregulare*) proved to be more beneficial for grapevine growth than the other two isolates, that were native to the soils where they were inoculated. In addition, some studies have shown that a diverse population of AMF promotes greater benefits to plants in terms of health and productivity than low diversity AMF populations (van Tuinen et al., 1998; Jeffries et al., 2003; Hector and Bagchi, 2007; Verbruggen and Kiers, 2010; Tian et al., 2013) since different species and genotypes of AMF may have a distinct effect on their hosts and can bring different ecological services (Gupta et al., 2000; Munkvold et al., 2004; Brígido et al., 2017). Consequently, the diversity of AMF communities is a key characteristic for a healthy and resilient agroecosystem, by virtue of the different kind of complementary functional benefits that each species can provide to the community, to the crop and to the soil, (Heijden et al. 1998; Munklovd et al., 2004; Khade and Rodrigues, 2009). However, although some studies, such as the ones mentioned above, demonstrate the inter and intraspecific differences on AMF behaviour and effects of on their hosts, understanding AMF functional diversity at population or community level requires far more research. Knowledge on this topic will be crucial for agriculture, since it will allow a proper management of AMF communities in the soil, to harness all the benefits they can provide to the main crop.

3.4. Mycorrhizal Fungi in Viticulture

3.4.1. Arbuscular Mycorrhizal Fungal Communities in Vineyards

Glomus is undoubtedly the genus that is most frequently found in vineyards (Karagiannidis et al., 1997; Magumo et al., 2010; Cesaro et al., 2021). In the study of Balestrini et al. (2010), *Glomus irregulare* (today known as *R. irregulare*) was the only phylotype found within the studied vineyards. In Burgundy vineyards under a variety of soil conditions management regimes (16 plots in total), the most common AMF found in soils belonged as well to *R. irregulare* species, demonstrating to be an 'ubiquitous species' in vineyards (Bouffaud et al., 2016). This species is indeed recognized as widely distributed in very different ecosystems (Öpik et al., 2006; Köhl et al., 2016), and it presents a high functional diversity and adaptability (Morin et al., 2019). Other studies have also shown the predominance of this species, as well as species from Glomeraceae family in vineyards (Likar et al., 2013; Schreiner and Mihala, 2017; Nogales et al., 2021).

Despite the presence of AMF in multiple soil types, colonization rates and species diversity highly depend on soil physicochemical properties (Zubek et al., 2012; Bouffaud et al., 2016). For instance, Bouffaud et al. (2016) showed a negative correlation between AMF population and vineyard

soil clay content, probably due to the lower aeration and oxygen concentration that it provides to the soil, compromising hyphal growth. In the same study, a significant correlation between mycorrhizal colonization and nutrient availability was also found. Generally, higher P concentration in the soil is related to a lower root AMF colonization level (Smith and Read, 2008). Soil pH also affects AMF development, due to its influence on nutrient availability (Sivakumar, 2013). For instance, Schreiner and Liderman (2005) on a study of AMF colonization in dryland vineyard in Oregon, concluded that in soils with pH below 5.5 and with a small use of foliar P fertilizers mycorrhizal colonization was highly stimulated.

Besides soil properties, agricultural practices are an important factor for the effectiveness and survival of AMF (Douds and Millner, 1999). Although AMF can be found in almost every soil, some agricultural practices, mostly the ones involving an intensive soil management, may suppress root colonization (Sieverding et al., 1991; Kabir et al., 1997). However, under more sustainable soil management, i.e., no-tillage, the use of cover vegetation and the limited use of fertilizers, an improved AMF development has been shown (Kabir, 2005; Brito et al., 2012; Oehl and Koch, 2018). Brito et al. (2012) studied the impact of tillage system on arbuscular mycorrhiza in a wheat field. Conventional tillage reduced AMF diversity by 40% when compared to no-till. Moreover, the frequency of operational taxonomic units (OTUs) found in soil differed between treatments, indicating that AMF are vulnerable to soil disturbance in various ways. Later, Oehl and Koch (2018) demonstrated substantially higher AMF spore density, species richness and diversity in no-tillage rows compared to tilled vineyards in conventional management. In fact, soil disturbances damages AMF ERM (Jasper et al., 1989; Evans and Miller, 1990; Brito et al., 2012).

On the other hand, it has also been demonstrated that the use of cover crops in vineyards promotes a higher AMF species richness (Bowles et al., 2017). As obligatory biotroph, AMF need living plants to proliferate (Smith and Read, 2008), and host identity has a strong impact on AMF fitness (Ehinger et al., 2009). Hence, a higher number of different host types in a vineyard, belonging to different species, is also expected to increment AMF richness. In previous studies, the effect of a variety of crop species on AMF colonization and abundance in soils was discovered due to host preferences that shape soil AMF communities (Jansa et al., 2002; Vestberg et al., 2005).

In organic vineyards weed control is normally done by the establishment of cover crops. Although this practice is expected to improve in AMF population (Soti et al., 2016), this is not always the case. Organically managed soils have high amount of nutrients like P, and therefore, AMF proliferation can be as limited as in conventional soils (Smith and Read, 2008; Van Geel et al., 2017). In fact, Van Geel et al., (2017), analysed AMF communities in 170 grapevine root samples from 18 conventionally managed and 16 organically managed vineyards in Belgium and the Netherlands. Organic management did not improve AMF diversity, rather, it was observed that soil P concentration

and acidity had significant detrimental effects on AMF diversity in those cases. In other cases, the planted cover crop species can have a strong influence on AMF proliferation in vineyards, with unexpected negative results. For example, AMF root colonization could be suppressed by some cover crop plant root exudates. De Deyn et al., 2009 investigated the impact of root allelochemicals on *Plantago lanceolata*. Although it functions as a defence mechanism, the authors determined that its root exudation (iridoid glycoside) does not limit the potential advantage of symbioses with AMF. The subject of how secondary metabolites influence the colonization of a nearby plant, such as grapevine, remained unclear. Because *P. lanceolata* is a poor host, it may minimize AMF colonization in grapevine. Radić et al. (2012) findings revealed that having this plant species as a neighbour inhibited the growth of grapevine mycorrhizae. On the other hand, *Tanacetum cinerariifolium*, was a helpful grapevine neighbour in terms of AMF development. The authors demonstrated that grapevine does not always have the same ability to interact with AMF, which is influenced by its surroundings. The essential and distinctive properties of each plant species are vital in these connections, and diverse allelopathic effects may arise (Mallik and Williams, 2005). Hence, cover crops may assist with AMF communities in vineyards, nevertheless, cover crops specie and soil nutritional status must be taken into account.

4. Grapevine Field-Inoculation of Arbuscular Mycorrhizal Fungi – Establishment of Inoculated Under-Vine Cover Crops

As said before, in intensively managed agricultural lands, low AMF abundance, diversity, and root colonization rates can be observed (Köhl et al., 2016) (Helgason et al., 1998; Verbruggen et al., 2010), since the excessive chemical inputs and tillage are detrimental for beneficial soil microbial populations (Jensa et al., 2006). Therefore, when a transition to more sustainable agricultural practices aims to be done, AMF inoculation can be a solution for circumventing the limitation of low soil AMF propagule density and diversity. In addition, inoculation of AMF gives the opportunity to select the most suited AMF species for each host genotype or soil environment. In the case of vineyards, Oehl and Koch (2018) stated that they often have low AMF abundance as well as low root colonization level, and in such cases, grapevines could profit more from the benefits that provided by a well-selected AMF isolate. Today, many companies produce selected AMF commercially (e.g. Atens, SYMPLANTA, INOQ, Mycorrhizal Applications, Inc, Symbiom, Mycovitro), that are well-adapted to a wide variety of soils and hosts.

Many authors, who studied the effect of arbuscular mycorrhizae in agricultural crops, proposed AMF soil inoculations as a sustainable strategy to improve plant growth and tolerance against environmental stress factors (Köhl et al., 2016; Popescu, 2016). Camprubrí et al. (2008) for

instance, confirmed mycorrhiza-induced protection of grapevines against *Armillaria mellea*, although differences were observed among the different AMF isolates that were inoculated (Camprubrí et al., 2008). Similar conclusions were obtained in different studies where AMF inoculation was done in grapevines, which included an improvement in grapevine growth, nutrition, and stress tolerance under field conditions (Aguín et al., 2004; Karagiannidis et al. 2007; Nogales et al., 2009a,b; 2021) (Table 3).

In general, there are three different methods for introducing AMF in vineyard soils: pre-inoculation in nursery conditions and further transplant to the field; direct field inoculation or indirect AMF inoculation through mycorrhizal donor plants- MDP (Nogales et al., 2008, 2009a, 2021).

The first method is suitable when installing new vineyards, since the already colonized grapevines can show improved growth and less mortality after plantation (Nogales et al., 2008; Calvet et al., 2007; Eftekhari, 2010), however, this implies an increased nursery costs. The direct field inoculation is an easier way to inoculate plants under field conditions, and it is also recommended for new plantations and for replating dead grapevines in already established vineyards. Inoculation can be done by directly placing the inoculum in the planting hole or by fertirrigation, for example. However, it has the disadvantage that spore germination is not guaranteed, since some fungi may not be adapted to the new soil conditions, which hinders grapevine colonization (Nogales et al., 2008). For this reason, the effectiveness can be lower (Nogales et al., 2008, 2009a).

The last inoculation technique represents an indirect AMF inoculation method through MDP. This technique is based on the knowledge that AMF form ERM networks in the soil that are common to different plant individuals, of the same species, or from a different species (Cheng and Baumgartner, 2005). Previous studies have used *Lavandula officinalis* and *Thymus vulgaris* and *Secale cereale* as MDP in vineyards (Nogales et al., 2009; Nogales et al., 2021). In both studies, an increase in AMF propagule density was observed. In Nogales et al. (2021), rye plants were established as cover crops, with the aim of harnessing all the benefits of green covers for grapevines and for soil health, while improving AMF propagule content through the inoculation of a selected species. Moreover, grapevine colonization of new AMF taxa other than the inoculated *Funneliformis mosseae* species was favoured.

This method represents a great opportunity to compensate cover crops' disadvantage of competition and creates an improved ecology and network around vineyards. It was shown before that the cover crops species generate positive effect on AMF. The research presented by Nogales et al. (2021) showed that inoculating grapevines with *F. mosseae* AMF species through donor plants is a viable field inoculation strategy that can help them endure better heat waves. However, there was too much competition between the cover crop and the grapevines, resulting in a reduction in vigour, which resulted in significant production losses in the case of a heat wave occurrence. Other types of cover crops, such as a mix of slow-growing legumes and grasses with high germination rates in the target soil and hence strong soil coverage, could be a more suitable alternative. This will help grape-growers to

reduce the number of interventions (e.g. mowing) required in the vineyard to maintain the green cover under control. The choice perennial cover crop species would have also been advantageous to avoid the need of planting the cover crop every year. Sowing disturbs the superficial soil, breaking the new ERM produced by the inoculated AMF species, and consequently delaying proper grapevine colonization. Another aspect that could be improved in future experiments is the way by which the of cover crop was inoculated. Instead of delivering the AMF inoculum straight to the soil beneath the rye seeds, the AMF inoculum could be applied as seed coating (Rocha et al., 2019), reducing the laboriousness of mycorrhizal cover crop installation.

5. Conclusion

Cover crops are beneficial in a variety of ways, particularly for the soil, and help to conserve or improve soil properties that indirectly also benefit the main crop, grapevine. The enhancement of mycorrhizal propagules in the soil is one of these properties, which is due in part to an increased number of hosts, apart from grapevines. On the other hand, AMF inoculation can provide multiple advantages to grapevines, including a better nutrition and tolerance against environmental stress factors. Therefore, the combination of both strategies, i.e., AMF inoculation and green cover establishment, is expected to produce synergic beneficial effects in vineyards, especially in the ones with degraded soils or containing low AMF propagules density. Mycorrhizal inoculation through cover covers is also expected to be of great advantage in vineyards that are transition to organic management, as this strategy can foster a faster recovery of oil health.

However, to harness all the benefits that the establishment of mycorrhizal cover crops can provide to viticulture, important factors such as the species to be planted and soil properties, as well as characteristics and objectives of each production system, should be carefully considered. Otherwise, undesired side effects (an excessive vigour decrease) may be detrimental for grapevine production. Hence, future studies on the correct implementation of AMF-inoculated under-vine cover crops in Mediterranean vineyard, including different cover crop species and inoculum delivery strategies (e.g. seed coating) are still necessary for an optimal implementation of this attractive soil management technique.

References

Abad, F.J., Marín Ederra, D., Santesteban García, G., Cibriain Sabalza, F., Sagüés Sarasa, A. 2020. Under-vine cover crops: impact on weed development, yield and grape composition. *Oeno One.* 54(4): 975–983.

Abad, J., Mendoza, I.H., Maín, D., Orcaray, L., Santeseban, L.G. 2021. Cover crops in viticulture. A systematic review (1): Implications on soil characteristics and biodiversity in vineyards. *OENO One.* 1: 295-312.

Abbott L. and Robson A. 1982. Infectivity of vesicular arbuscular mycorrhizal fungi in agricultural soils. *Australian Journal of Agricultural Research.* 33: 1049–1059.

Adams, K E. 2011. Influence of vineyard floor management practices on soil aggregate stability, total soil carbon and grapevine yield. *Faculty of California Polytechnic State University, San Luis Obispo.*

Agudelo, M.B., Meyer, E., Lovato, P.E. 2020. Growth, heavy metal uptake, and photosynthesis in'Paulsen 1103'(Vitis berlandieri x rupestris) grapevine rootstocks inoculated with arbuscular mycorrhizal fungi from vineyard soils with high copper contents. *Vitis: Journal of Grapevine Research.* 59(4): 169-180.

Aguin, O., Mansilla, J.P., Vilarino, A., Sainz, M.J. 2004. Effects of mycorrhizal inoculation on root morphology and nursery production of three grapevine rootstocks. *American Journal of Enology and Viticulture.* 55: 108–111.

Akiyama K, Matsuzaki K, Hayashi H. 2005. Plant sesquiterpenes induce hyphal branching in arbuscular mycorrhizal fungi. *Nature.* 435:824–27.

Alikadic, A., Pertot, I., Eccel, E., Dolci, C., Zarbo, C., Caffarra, A., De Filippi, R., Furlanello, C. 2019. The impact of climate change on grapevine phenology and the influence of altitude: A regional study. *Agricultural and forest meteorology.* 271: 73-82.

Allen, T.R., Millar, T., Berch, S.M., Berbee, M.L. 2003. Culturing and direct DNA extraction find different fungi from the same ericoid mycorrhizal roots. *New Phytologist,* 255-272.

Alonso, R., Berli, F.J., Fontana, A., Piccoli, P., Bottini, R. 2016. Malbec grape (*Vitis vinifera* L.) responses to the environment: Berry phenolics as influenced by solar UV-B, water deficit and sprayed abscisic acid. Plant Physiology and Biochemistry. 109: 84-90

Alori, E.T., Dare, M.O., Babalola, O.O. 2017. Microbial inoculants for soil quality and plant health. *In* Sustainable Agriculture Reviews. pp. 281–307. Springer, Cham.

Álvarez-Pérez, J.M., González-García, S., Cobos, R., Olego, M.Á., Ibañez, A., Díez-Galán, A., Garzón-Jimeno, E., Coque, J.J.R. 2017. Use of endophytic and rhizosphere actinobacteria from grapevine plants to reduce nursery fungal graft infections that lead to young grapevine decline. *Applied and environmental microbiology.* 83(24): e01564-17.

Amendola, C., Montagnoli, A., Terzaghi, M., Trupiano, D., Oliva, F., Baronti, S., Miglietta, F., Chiatante, D., Scippa, G.S. 2017. Short-term effects of biochar on grapevine fine root dynamics and arbuscular mycorrhizae production. *Agriculture, Ecosystems & Environment.* 23: 236-245.

Andreolli, M., Lampis, S., Zapparoli, G., Angelini, E., Vallini, G. 2016. Diversity of bacterial endophytes in 3 and 15 year-old grapevines of Vitis vinifera cv. Corvina and their potential for plant growth promotion and phytopathogen control. *Microbiological research*. 183: 42-52.

Andrino, A., Guggenberger, G., Sauheitl, L., Burkart, S., Boy, J. 2021. Carbon investment into mobilization of mineral and organic phosphorus by arbuscular mycorrhiza. *Biology and Fertility of Soils.* 57(1): 47-64.

Arruda, B., Herrera, W.F.B., Rojas-García, J.C., Turner, C., Pavinato, P.S. 2021. Cover crop species and mycorrhizal colonization on soil phosphorus dynamics. *Rhizosphere*. 19: 100396.

Artursson, V., Finlay, R D., Jansson, J.K. 2006. Interactions between arbuscular mycorrhizal fungi and bacteria and their potential for stimulating plant growth. *Environmental microbiology*. 8(1): 1-10.

Augé, R.M. 2001. Water relations, drought and vesicular-arbuscular mycorrhizal symbiosis. *Mycorrhiza*. 11(1): 3-42.

Augé, R.M., Stodola, A.J., Tims, J.E., Saxton, A.M. 2001. Moisture retention properties of a mycorrhizal soil. *Plant and Soil*. 230(1): 87-97.

Augé, R.M. 2004. Arbuscular Mycorrhizae and Soil/Plant Water Relations. *Canadian Journal of Soil Science*. 84(4): 373-381.

Augé, R.M., Toler, H.D., Saxton, A.M. 2015. Arbuscular mycorrhizal symbiosis alters stomatal conductance of host plants more under drought than under amply watered conditions: a meta-analysis. *Mycorrhiza.* 25: 13–24.

Austin, C.N., Grove, G.G., Meyers, J.M., Wilcox, W.F. 2011. Powdery mildew severity as a function of canopy density: associated impacts on sunlight penetration and spray coverage. *American journal of enology and viticulture*. 62(1): 23-31.

Avio, L., Pellegrino, E., Bonari, E., Giovannetti, M. 2006. Functional diversity of arbuscular mycorrhizal fungal isolates in relation to extraradical mycelial networks. *New Phytologist*. 172(2): 347-357.

Azcón-Aguilar, C., Barea, J.M. 1997. Arbuscular mycorrhizas and biological control of soil-borne plant pathogens–an overview of the mechanisms involved. *Mycorrhiza*. 6(6): 457-464.

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.

Bago, B., Vierheilig, H., Piché, Y., Azcón-Aguilar, C. 1996. Nitrate depletion and pH changes induced by the extraradical mycelium of the arbuscular mycorrhizal fungus Glomus intraradices grown in monoxenic culture. *New phytologist*. 133(2): 273-280.

Bago, B., Pfeffer, P., Shachar-Hill, Y. 2000. Carbon metabolism and transport in arbuscular mycorrhizas. *Plant Physiology.* 124: 949–57.

Bajpai, A., Rawat, S., Johri, B.N. 2019. Fungal diversity: global perspective and ecosystem dynamics. *In* Microbial Diversity in Ecosystem Sustainability and Biotechnological Applications (pp. 83-113). Springer, Singapore.

Baldock, J.A., and Nelson, P.N. 2000. Soil organic matter. *In* Handbook of Soil Science. Sumner, Malcolm E., (ed.) CRC Press, Boca Raton, FL, USA, B25-B84.

Balestrini, R., Magurno, F., Walker, C., Lumini, E., Bianciotto, V. 2010. Cohorts of arbuscular mycorrhizal fungi (AMF) in Vitis vinifera, a typical Mediterranean fruit crop. *Environmental Microbiology Reports*. 2(4): 594-604.

Balint, G., Reynolds, A.G. 2013. Impact of exogenous abscisic acid on vine physiology and grape composition of Cabernet Sauvignon. *American journal of enology and viticulture.* 64(1): 74-87.

Balzergue, C., Puech-Pagès, V., Bécard, G., Rochange, S.F. 2010. The regulation of arbuscular mycorrhizal symbiosis by phosphate in pea involves early and systemic signalling events. *Journal of Experimental Botany.* 62(3): 1049–1060.

Barea, J. M. 1997. Interaction between mycorrhizal fungi and rhizosphere micro-organisms with in the context of sustainable soil-plant systems. *Multitrophic interactions in terrestrial systems*. 65-67.

Barea, J.M., Pozo, M.J., Azcon, R., Azcon-Aguilar, C. 2005. Microbial co-operation in the rhizosphere. *Journal of experimental botany*. 56(417): 1761-1778.

Barrios, E. 2007. Soil biota, ecosystem services and land productivity. *Ecological economics.* 64(2): 269-285.

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.

Baslam, M., Goicoechea, N. 2012. Water deficit improved the capacity of arbuscular mycorrhizal fungi (AMF) for inducing the accumulation of antioxidant compounds in lettuce leaves. *Mycorrhiza*. 22: 347–359.

Bates, T.R., Dunst, R.M., Joy, P. 2002. Seasonal dry matter, starch, and nutrient distribution in 'Concord' grapevine roots. *HortScience*. 37(2): 313-316.

Battany, M.C., Grismer, M.E., 2000. Rainfall runoff and erosion in Napa Valley vineyards: effects of slope, cover and surface roughness. *Hydrological Processes*. 14: 1289–1304.

Bedini, S., Pellegrino, E., Avio, L., Pellegrini, S., Bazzoffi, P., Argese, E., Giovannetti, M. 2009. Changes in soil aggregation and glomalinrelated soil protein content as affected by the arbuscular mycorrhizal fungal species Glomus mosseae and Glomus intradices. *Soil Biology and Biochemistry.* 41:1491–1496.

Begon M., Harper J.L., Townsend, C.R. 1996. *In* Ecology: Individuals, Populations and communities (3rd Ed.). Blackwell Science, Oxford, UK.

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.

Begum, N., Qin, C., Ahanger, M.A., Raza, S., Khan, M.I., Ashraf, M., Ahmed, N., Zhang, L. 2019. Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. Frontiers in Plant Science. 10: 1068.

Belew, D., Astatkie, T., Mokashi, M.N., Getachew, Y., Patil, C.P. 2010. Effects of salinity and mycorrhizal inoculation (Glomus fasciculatum) on growth responses of grape rootstocks (Vitis spp.). *South African Journal of Enology and Viticulture*. 31(2): 82-88.

Belmonte, S. A., Celi, L., Stahel, R. J., Bonifacio, E., Zanni, 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.

Berendsen, R.L., Pieterse, C. M., Bakker, P.A. 2012. The rhizosphere microbiome and plant health. *Trends in plant science*. 17(8): 478-486.

Bergkvist, G., Stenberg, M., Wetterlind, J., Båth, B., Elfstrand, S. 2011. Clover cover crops under-sown in winter wheat increase yield of subsequent spring barley—Effect of N dose and companion grass. *Field Crops Research*. 120(2): 292-298.

Berta, G., Fusconi, A., Hooker, J. E. 2002. Arbuscular mycorrhizal modifications to plant root systems: scale, mechanisms and consequences. *In* Mycorrhizal technology in agriculture. S. Gianinazzi, H. Schüepp, J. M. Barea, and K. Haselwandter (eds.) (pp. 71-85). Birkhäuser, Basel.

Birhane, E., Sterck, F.J., Fetene, M., Bongers, F., Kuyper, T.W. 2012. Arbuscular mycorrhizal fungi enhance photosynthesis, water use efficiency, and growth of frankincense seedlings under pulsed water availability conditions. *Oecologia*. 169(4): 895-904.

Blanco-Canqui, H., Mikha, M.M., Presley, D.R., Claassen, M.M. 2011. Addition of cover crops enhances no-till potential for improving soil physical properties. *Soil Science Society of America Journal*. 75(4): 1471-1482.

Blanco-Canqui, H. 2013. Crop residue removal for bioenergy reduces soil carbon pools: How can we offset carbon losses? *Bioenergy Research*. 6(1): 358-371.

Blanco-Canqui, H., Shaver, T.M., Lindquist, J.L., Shapiro, C.A., Elmore, R.W., Francis, C.A., Hergert, G.W. 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. *Agronomy journal*. 107(6): 2449-2474.

Bock, A., Sparks, T., Estrella, N., Menzel, A. 2011. Changes in the phenology and composition of wine from Franconia, Germany. *Climate Research*. 50(1): 69-81.

Bois, B., Zito, S., Calonnec, A. 2017. Climate vs grapevine pests and diseases worldwide: the first results of a global survey. *OENO one*. 51(2-3): 133-139.

Bona, E., Massa, N., Novello, G., Boatti, L., Cesaro, P., Todeschini, V., Magnelli, V., Manfredi, M., Marengo, E., Mignone, F., Berta, G., Lingua, G., Gamalero, E. 2019. Metaproteomic characterization of the Vitis vinifera rhizosphere. *FEMS microbiology ecology.* 95(1): fiy204.

Botton, B. and Chalot, M. 1995. Nitrogen assimilation: enzymology and ectomycorrhizas. *In* Miycorrhiza: structure, function, molecular biology and biotechnology. Varma, A., Hock, B. (ed) pp. 325-363. Berlin, Germany: Springer-Verlag

Bouby, L., et al. 2021. Tracking the history of grapevine cultivation in Georgia by combining geometric morphometrics and ancient DNA. *Vegetation History and Archaeobotany*. 30(1): 63-76.

Bouffaud, M.L, Bernaud, E., Colombet, A., Van Tuinen, D., Wipf, D., Redecker, D. 2016. Regional-scale analysis of arbuscular mycorrhizal fungi: The case of Burgundy vineyards. *Journal International des Sciences de la Vigne et du Vin.* 50(1): 1-8.

Bouzas-Cid, Y., Portu, J., Pérez-Álvarez, E.P., Gonzalo-Diago, A., Garde-Cerdán, T. 2016. Effect of vegetal ground cover crops on wine anthocyanin content. *Scientia Horticulturae*. 211: 384-390.

Bowles, T.M., Barrios-Masias, F.H., Carlisle, E.A., Cavagnaro, T.R., and Jackson, L.E. 2016. Effects of arbuscular mycorrhizae on tomato yield, nutrient uptake, water relations, and soil carbon dynamics under deficit irrigation in field conditions. *Science of The Total Environment.* 566: 1223–1234.

Bowles, T.M., Jackson, L.E., Loeher, M., Cavagnaro, T.R. 2017. Ecological intensification and arbuscular mycorrhizas: a meta-analysis of tillage and cover crop effects. *Journal of Applied Ecology*. 54(6): 1785-1793.

Brígido, C., van Tuinen, D., Brito, I., Alho, L., Goss, M. J., Carvalho, M. 2017. Management of the biological diversity of AM fungi by combination of host plant succession and integrity of extraradical mycelium. *Soil Biology and Biochemistry*. 112: 237-247.

Brito, I., Goss, M. J., de Carvalho, M. Chatagnier, O., Van Tuinen, D. 2012. Impact of tillage system on arbuscular mycorrhiza fungal communities in the soil under Mediterranean conditions. *Soil and Tillage Research.* 121: 63-67.

Brito, I., Carvalho, M., Goss, M.J. 2013. Soil and weed management for enhancing arbuscular mycorrhiza colonization of wheat. *Soil Use Management.* 29: 540–546.

Bruisson, S., Maillot, P., Schellenbaum, P., Walter, B., Gindro, K., Deglène-Benbrahim, L. 2016. Arbuscular mycorrhizal symbiosis stimulates key genes of the phenylpropanoid biosynthesis and stilbenoid production in grapevine leaves in response to downy mildew and grey mould infection. *Phytochemistry*. 131: 92-99.

Brundrett, M. 2004. Diversity and classification of mycorrhizal associations. *Biological Reviews*. 79(3): 473-495.

Brunetto, G., Rosa, D.J., Ambrosini, V.G., Heinzen, J., Ferreira, P. A., Ceretta, C.A., Soares, C., Melo, G., Soriani, H.H., Nicoloso, F.T., Farias, J.G., De Conti, L., Silva, L., Couto, R.R., Jacques, R., Tiecher, T. L. 2019. Use of phosphorus fertilization and mycorrhization as strategies for reducing copper toxicity in young grapevines. *Scientia Horticulturae*. 248: 176-183.

Bucher, M. 2007. Functional biology of plant phosphate uptake at root and mycorrhiza interfaces. *New Phytologist.* 173: 11–26.

Cakmak, I., Hengeler, C., Marschner, H. 1994. Changes in phloem export of sucrose in leaves in response to phosphorus, potassium and magnesium deficiency in bean plants. *Journal of Experimental Botany*. 45(9): 1251-1257.

Cakmak, I. 2013. Magnesium in crop production, food quality and human health. *Plant and Soil*. 368: 1-4.

Calleja-Cervantes, M.E.; Fernández-González, A.J.; Irigoyen, I.; Fernández-López, M.; Aparicio-Tejo, P.M., Menéndez, S. 2015. Thirteen years of continued application of composted organic wastes in a vineyard modify soil quality characteristics. *Soil Biology and Biochemistry*. 90: 241–254.

Calvet, C., Pinochet, J., Camprubí, A., Fernández, C. 1995. Increased tolerance to the root-lesion nematode Pratylenchus vulnus in mycorrhizal micropropagated BA-29 quince rootstock. *Mycorrhiza*. 5(4): 253-258.

Calvet, C., Camprubí, A., Estaún, V., Luque, J., De Herralde, F., Biel, C., Savé, R., Garcia- Figueres, F., 2007. Aplicación de la simbiosis micorriza arbuscular al cultivo de la vid. Viticultura Enologia Profesional. 110: 1-7

Cameron, D.D., Neal, A.L., van Wees, S.C., Ton, J. 2013. Mycorrhiza-induced resistance: more than the sum of its parts?. *Trends in plant science*. 18(10): 539-545.

Camprubí, A., Estaún, V., Nogales, A., García-Figueres, F., Pitet, M., Calvet, C. 2008. Response of the grapevine rootstock Richter 110 to inoculation with native and selected arbuscular mycorrhizal fungi and growth performance in a replant vineyard. *Mycorrhiza*. 18(4): 211-216.

Capó-Bauçà, S., Marqués, A., Llopis-Vidal, N., Bota, J., Baraza, E. 2019. Long-term establishment of natural green cover provides agroecosystem services by improving soil quality in a Mediterranean vineyard. *Ecological Engineering.* 127: 285-291.

Carbonnel, S. and Gutjahr, C. 2014. Control of arbuscular mycorrhiza development by nutrient signals*. Frontiers in Pant Science*. 5: 1-5.

Castiglione, S., Franchin, C., Fossati, T., Lingua, G., Torrigiani, P., Biondi, S., 2007. High zinc concentrations reduce rooting capacity and alter metallothionein gene expression in white poplar (Populus alba cv. Villafranca). *Chemosphere*. 67: 1117–1126.

Cavagnaro, T.R., Smith, F.A., Smith, S.E., Jakobsen, I. 2005. Functional diversity in arbuscular mycorrhizas: Exploitation of soil patches with different phosphate enrichment differs among fungal species. *Plant Cell Environ.* 28: 642–650.

Cavagnaro, T.R., Jackson, L.E., Six, J., Ferris, H., Goyal, S., Asami, D., Scow, K.M. 2006. Arbuscular mycorrhizas, microbial communities, nutrient availability, and soil aggregates in organic tomato production. *Plant and Soil*. 282(1): 209-225.

Cavagnaro, T.R. 2008. The role of arbuscular mycorrhizas in improving plant zinc nutrition under low soil zinc concentrations: a review. *Plant and Soil*. 304(1): 315-325.

Celette, F., Gaudin, R., Gary, C., 2008. Spatial and temporal changes in the water regime of a Mediterranean vineyard due to the adoption of cover cropping. *European Journal of Agronomy.* 29: 153–162.

Celette, F., Findeling, A., Gary, C., 2009. Intercropping and dynamics of nitrogen in a naturally poor system: the case of an association of grapevine and grass cover under Mediterranean climate. *European Journal of Agronomy.* 30: 41–51.

Cerdà, A., Imeson, A.C., Poesen, J. 2007. Soil water erosion in rural areas. *Catena*. 71: 191–266.

Cerdà, A. 2009. Soil Erosion and Agriculture. Soil & Tillage Research. 106: 107–108

Cesaro, P., Massa, N., Bona, E., Novello, G., Todeschini, V., Boatti, L., Mignone, F., Gamalero, El., Verta, G., Lingua, G. 2021. Native AMF Communities in an Italian Vineyard at Two Different Phenological Stages of Vitis vinifera. *Frontiers in Microbiology*. 1792.

Chaves, M.M., Santos, T.P., Souza, C.D., Ortuño, M.F., Rodrigues, M.L., Lopes, C.M., Mroco, J.P., Pereira, J.S. 2007. Deficit irrigation in grapevine improves water-use efficiency while controlling vigour and production quality. *Annals of applied biology*. 150(2): 237-252.

Chen, G., and R.R. Weil. 2010. Penetration of cover crop roots through compacted soils. Plant Soil. 331: 31–43.

Chen, H., et al. 2019. Effects of intercropping with floricultural accumulator plants on cadmium accumulation in grapevine. *Environmental Science and Pollution Research*. 26(24): 24474-24481.

Cheng, X., Baumgartner, K. 2004. Arbuscular mycorrhizal fungi-mediated nitrogen transfer from vineyard cover crops to grapevines. *Biology and fertility of soils*. 40(6): 406-412.

Cheng, X., Baumgartner, K. 2005. Overlap of grapevine and cover-crop roots enhances interactions among grapevines, cover crops, and arbuscular mycorrhizal fungi. *In* Soil Environment and Vine Mineral Nutrition: Symposium Proceedings and Related Papers. San Diego, CA: American Society of Enology and Viticulture. 171-174

Chou, M.Y., Heuvel, J.E.V. 2019. Annual under-vine cover crops mitigate vine vigor in a mature and vigorous cabernet franc vineyard. *American Journal of Enology and Viticulture*. 70(1): 98-108.

Cifre, J., Bota, J., Escalona, J.M., Medrano, H., Flexas, J. 2005. Physiological tools for irrigation scheduling in grapevine (*Vitis vinifera* L.): An open gate to improve water-use efficiency?. *Agriculture, Ecosystems & Environment*. 106(2-3): 159-170.

Clar, R.B., and Zeto, S.K. 2000. Mineral acquisition by arbuscular mycorrhizal plants. *Journal of Plant Nutrition*. 23: 876-902.

Colugnati, G., G. Cattarossi, and G. Crespan. 2004. Gestione del terreno in viticoltura. *Vigne Vini*. 11: 53-83.

Conde, C., Silva, P., Fontes, N., Dias, A. C. P., Tavares, R. M., Sousa, M. J., Agase, A., Delrot, S., Gerós, H. 2007. Biochemical changes throughout grape berry development and fruit and wine quality. *Food.* 1: 1–22.

Coniberti, A., Ferrari, V., Disegna, E., Petillo, M.G., Lakso, A.N. 2018. Under-trellis cover crop and planting density to achieve vine balance in a humid climate. *Scientia Horticulturae*. 227: 65-74.

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.

De Baets, S., Poesen, J., Knapen, A., Galindo Morales, P. 2007. Impact of root architecture, soil characteristics and flow shear stress on the erosion-reducing potential of roots during concentrated flow. *Earth Surface Processes and Landforms*. 32: 1323–1345.

De Baets, S., Poesen, J., Meersmans, J., Serlet, L. 2011. Cover crops and their erosion-reducing effects during concentrated flow erosion. *Catena*. 85(3): 237-244.

Dickson, S. 2004. The *Arum–Paris* continuum of mycorrhizal symbioses. *New Phytologist.* 163: 187-200.

Dodd, J. C., Boddington, C. L., Rodriguez, A., Gonzalez-chavez, C. 2000. Mycelium of Arbuscular Mycorrhizal fungi (AMF) from different genera : form , function and detection. *International Instituto of Biotechnology.* 226: 131-151.

Doran, J.W. 1980. Soil microbial and biochemical changes associated with reduced tillage. *Soil Science Society of America Journal*. 44(4): 765-771.

Douds Jr, D.D., Galvez, L., Janke, R.R., Wagoner, P. 1995. Effect of tillage and farming system upon populations and distribution of vesicular-arbuscular mycorrhizal fungi. *Agriculture, ecosystems & environment*. 52(2-3): 111-118.

Douds Jr, D.D., Millner, P.D. 1999. Biodiversity of arbuscular mycorrhizal fungi in agroecosystems. *Agriculture, ecosystems & environment*. 74(1-3): 77-93.

Douds, D.D., Johnson, N.C. 2007. Contributions of arbuscular mycorrhizas to soil biological fertility. *In* Soil biological fertility: a key to sustainable land use in agriculture. Abbott LK, Murphy DV (eds) pp. 129–162. Springer, Dordrecht.

Doran, J.W., Zeiss, M.R. 2000. Soil health and sustainability: managing the biotic component of soil quality. *Applied soil ecology.* 15(1): 3-11.

Duchene E., Schneider C. 2005. Grapevine and climatic changes: a glance at the situation in Alsace. *Agronomy for Sustainable Development*. 25: 93-99.

Eftekhari, M., Alizadeh, M., Mashayekhi, K., Asghari, H., Kamkar, B. 2010. Integration of arbuscular mycorrhizal fungi to grape vine (Vitis vinifera L.) in nursery stage. *Journal of Advanced Laboratory Research in Biology.* 1(1): 102-111.

Eftekhari, M., Alizadeh, M., Ebrahimi, P. 2012. Evaluation of the total phenolics and quercetin content of foliage in mycorrhizal grape (Vitis vinifera L.) varieties and effect of postharvest drying on quercetin yield. *Industrial Crops and Products*. 38: 160-165.

Ehinger, M., Koch, A.M., Sanders, I.R. 2009. Changes in arbuscular mycorrhizal fungal phenotypes and genotypes in response to plant species identity and phosphorus concentration. *New Phytologist*. 184(2): 412-423.

Ehrlich, P. R. 1997. The Population Bomb (1968). *New York: Sierra Club/Ballantine*.

Elmer, P.A., Michailides, T.J. 2007. Epidemiology of Botrytis cinerea in orchard and vine crops. *In* Botrytis: biology, pathology and control. pp. 243-272. Springer, Dordrecht.

Erisman, J.W., Sutton, M.A., Galloway, J., Klimont, Z., Winiwarter, W. 2008. How a century of ammonia synthesis changed the world. *Nature Geoscience*. 1: 636-639

Evans, D.G., Miller, M.H. 1990. The role of the external mycelial network in the effect of soil disturbance upon vesicular-arbuscular mycorrhizal colonization of maize*. New Phytologist*. 114: 65–71.

Facelli, E., Smith, S.E. and Smith F.A. 2009. Mycorrhizal symbiosis – Overview and New Insights Into Roles of Arbuscular Mycorrhizas in Agro- and Natural Ecosystems. *Australian Plant Pathology*. 38: 338-344.

Faria, C.M.B., J.M. Soares, and P.C.S. Leão. 2004. Adubação verde com leguminosas em videira no submédio São Francisco. *Revista Brasileira de Ciência do Solo*. 28: 641-648.

Fellbaum, C.R., Gachomo, E.W., Beesetty, Y., Choudhari, S., Strahan, G.D., Pfeffer, P.E., Kiers, T., Bucking, H. 2012. Carbon availability triggers fungal nitrogen uptake and transport in arbuscular mycorrhizal symbiosis. *PNAS - Proceedings of the National Academy of Sciences of the United States of America.* 109: 2666–2671.

Fernández, L. 2021. Global fertilizer consumption by nutrient 1965-2019. Statista website. https://www.statista.com/statistics/438967/fertilizer-consumption-globally-by-nutrient/

Fernandes de Oliveira, A., Serra, S., Ligios, V., Satta, D., Nieddu, G. 2021. Assessing the effects of vineyard soil management on downy and powdery mildew evelopment. *Horticulturae*. 7(8): 209.

Fernandes-Silva, A A., Ferreira, T.C., Correia, C.M., Malheiro, A.C., Villalobos, F.J. 2010. Influence of different irrigation regimes on crop yield and water use efficiency of olive. *Plant and soil.* 333(1): 35-47.

Ferrara, G., Nigro, D., Torres, R., Gadaleta, A., Fidelibus, M.W., Mazzeo, A. 2021. Cover crops in the inter-row of a table grape vineyard managed with irrigation sensors: effects on yield, quality and glutamine synthetase activity in leaves. *Scientia Horticulturae*. 281: 109963.

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 & Environment.* 256: 184–193.

Ferrol, N., González-Guerrero, M., Valderas, A., Benabdellah, K., Azcón-Aguilar, C. 2009. Survival strategies of arbuscular mycorrhizal fungi in Cu-polluted environments. *Phytochemistry Reviews*. 8(3): 551-559.

Ferrol, N., Tamayo, E., Vargas, P. 2016. The heavy metal paradox in arbuscular mycorrhizas: from mechanisms to biotechnological applications. *Journal of experimental botany*. erw403.

Fitter, A.H. 2004. Magnolioid roots — hairs, architecture and mycorrhizal dependency. *New Phytologist.* 164(1): 15–16.

Fleishman, S.M., Bock, H.W., Eissenstat, D.M., Centinari, M. 2021. Undervine groundcover substantially increases shallow but not deep soil carbon in a temperate vineyard. *Agriculture, Ecosystems & Environment.* 313: 107362

Folorunso, O.A., Rolston, D.E., Prichard, T., Louie, D.T. 1992. Soil surface strength and infiltration rate as affected by winter cover crops. Soil Technol. 5: 189–197.

Fraga, H., Malheiro, A.C., Santos, A.J., Pereira, J.M.M. 2012. Climate Change Projections for the Portuguese Viticulture Using a Multi-Model Ensemble. *Ciência e Técnica Vitivinícola*. 27(1): 39-48.

Frank, S.D., Shrewsbury, P.M. 2004. Effect of conservation strips on the abundance and distribution of natural enemies and predation of Agrotis ipsilon (Lepidoptera: Noctuidae) on golf course fairways. *Environmental Entomology.* 33(6): 1662-1672.

Frank, S.D., Shrewsbury, P.M., Esiekpe, O. 2008. Spatial and temporal variation in natural enemy assemblages on Maryland native plant species. *Environmental Entomology.* 37(2): 478-486.

Franken P. 2010. Molecular-physiological aspects of the AM symbiosis post penetration. *In* Arbuscular Mycorrhizas: Physiology and Function, Koltai, H., Kapulnik, Y. (eds). pp. 93–116. Berlin: Springer Verlag

Frey, D., and Moretti, M. 2019. A comprehensive dataset on cultivated and spontaneously growing vascular plants in urban gardens. *Data in brief*. 25: 103982.

Friese, C.,Allen, M.F. 1991. The spread of VA mycorrhizal fungal hyphae in the soil: inoculum types and external hyphal architecture. *Mycologia.* 83: 409–418.

Gachomo, E., Allen, J.W., Pfeffer, P.E., Govindarajulu, M., Douds, D.D., Jin, H., Nagahashi, G., Lammers, P.J., Shachar-Hill, Y. and Bücking, H. 2009. Germinating spores of *Glomus intraradices* can use internal and exogenous nitrogen sources for *de novo* biosynthesis of amino acids. *New Phytologist.* 184: 399-411.

Galati, A.; Gristina, L.; Crescimanno, M.; Barone, E.; Novara, A. 2015. Towards more efficient incentives for agri-environment measures in degraded and eroded vineyards. Land Degradation & Development. 26: 557–564.

García, I.V., Mendoza, R.E. 2007 Arbuscular mycorrhizal fungi and plant symbiosis in a saline-sodic soil. *Mycorrhiza.* 17:167–174.

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.

Garg, N., Chandel, S. 2010. Arbuscular mycorrhizal networks: process and functions. A review. *Agronomy for Sustainable Development*. 30(3): 581-599.

Genre, A., Chabaud, M., Faccio, A., Barker, D.G., Bonfante, P. 2008. Prepenetration apparatus assembly precedes and predicts the colonization patterns of arbuscular mycorrhizal fungi within the root cortex of both *Medicago truncatula* and *Daucus carota*. *Plant Cell.* 20: 1407–20.

Genre, A., Chabaud, M., Timmers, T., Bonfante, P., Barker, D.G. 2005. Arbuscular mycorrhizal fungi elicit a novel intracellular apparatus in *Medicago truncatula* root epidermal cells before infection. *Plant Cell.* 17: 3489–99.

Geoffrion, R. 1999. L'enherbement permanent, 40 ans aprés. *Phytoma.* 519: 25-27.

Gianinazzi, S., Gollotte, A., Binet, M.N., van Tuinen, D., Redecker, D., Wipf, D. 2010. Agroecology: The key role of arbuscular mycorrhizas in ecosystem services. *Mycorrhiza*. 20(8): 519-530.

Giese, G., Velasco-Cruz, C., Roberts, L., Heitman, J., Wolf, T.K. 2014. Complete vineyard floor cover crops favorably limit grapevine vegetative growth. *Scientia horticulturae.* 170: 256-266.

Giorgi, F., Lionello, P. 2008. Climate change projections for the Mediterranean region. *Global and planetary change*. 63(2-3): 90-104.

Giovannetti, M., Sbrana, C. 2001. Self and non-self responses in hyphal tips of arbuscular mycorrhizal fungi. *in* Cell biology of plant and fungal tip growth. Geitmann, A. (eds). IOS, Amsterdam. 221–231

Giri, B., Kapoor, R., Mukerji, K.G. 2003. Influence of arbuscular mycorrhizal fungi and salinity on growth, biomass, and mineral nutrition of Acacia auriculiformis. *Biology and Fertility of Soils*. 38(3): 170-175.

Giri, B., Mukerji, K.G. 2004. Mycorrhizal inoculant alleviates salt stress in Sesbania aegyptiaca and Sesbania grandiflora under field conditions: evidence for reduced sodium and improved magnesium uptake. *Mycorrhiza*. 14: 307–312.

Goldman, B.J., Clancy, K.L. 1991. A survey of organic produce purchases and related attitudes of food cooperative shoppers. *American Journal of Alternative Agriculture*. 6(2): 89-96.

Gomez, J.A., Llewellyn, C., Basch, G., Sutton, P.B., Dyson, J.S., Jones, C.A. 2011. The effects of cover crops and conventional tillage on soil and runoff loss in vineyards and olive groves in several Mediterranean countries. *Soil Use Management*. 27: 502–514.

González-Centeno, M. R., Chira, K., Miramont, C., Escudier, J.-L., Samson, A., Salmon, J. -M., Ojeda, H., Teissedre, P.-L. 2019. Disease resistant bouquet vine varieties: assessment of the phenolic, aromatic, and sensory potential of their wines. *Biomolecules*. 9: 793.

Govindarajulu, M., Pfeffer, P.E., Jin, H., Abubaker, J., Douds, D., Allen, J.W., Bucking, H., Lammers, P.J., Shachar-Hill, Y. 2005. Nitrogen transfer in the arbuscular mycorrhizal symbiosis. *Nature.* 435: 819-823.

Green, J.L.; Holmes, A.J., Westoby, M., Oliver, I., Briscoe, D., Dangerfield, M., Gillings, M., Beattie, A.J. 2004. Spatial scaling of microbial eukaryote diversity. *Nature*. 432: 747–750.

Greer, D.H., Weston, C. 2010. Heat stress affects flowering, berry growth, sugar accumulation and photosynthesis of Vitis vinifera cv. Semillon grapevines grown in a controlled environment. *Functional Plant Biology.* 37(3): 206-214.

Guerra, B., Steenwerth, K. 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.

Gupta, V., Satyanarayana, T., Garg, S. 2000. General aspects of mycorrhiza. In Mycorrhizal Biology. Mukerji, K.G., Chamola, B.P., Singh, J.E. (Eds.). pp. 27-44. Kluwer Academic/Plenum.

Gutjahr, C., Parniske, M. 2013. Cell and developmental biology of arbuscular mycorrhiza symbiosis. *Annual review of cell and developmental biology*. 29: 593-617.

Gutjahr, C., Paszkowski, U. 2013. Multiple control levels of root system remodeling in arbuscular mycorrhizal symbiosis. *Frontiers in Plant Science*. 4: 204.

Hallenn, F., Crous, P.W. 2006. A review of black foot disease of grapevine. *A Review of Black Foot Disease of Grapevine*. 1000-1013.

Harrison, MJ, Dixon, RA. 1994. Spatial patterns of expression of flavonoid/isoflavonoid pathway genes during interactions between roots of Medicago truncatula and the mycorrhizal fungus Glomus versiforme. *Plant Journal*. 6: 9–20.

Harrison, M.J. 1997. The arbuscular mycorrhizal symbiosis: an underground association. *Trends in Plant Science.* 2: 54–56.

Harrison, M.J. 2012. Cellular programs for arbuscular mycorrhizal symbiosis. *Current Opinion in Plant Biology.* 15:691–98

Hart, M.M., Reader, R.J., Klironomos, J.N. 2001. Life-history strategies of arbuscular mycorrhizal fungi in relation to their successional dynamics. *Mycologia*. 93(6): 1186-1194.

Hart, M. M. 2002. *Life history strategies of arbuscular mycorrhizal fungi* (Doctoral dissertation).

Hart, M.M., Reader, R.J. 2002. Does percent root length colonization and soil hyphal length reflect the extent of colonization for all AMF?. *Mycorrhiza.* 12(6): 297-301.

Hatch, T.A., Hickey, C.C., Wolf, T.K. 2011. Cover crop, rootstock and root restriction regulate vegetative growth of Cabernet Sauvignon in a humid environment. American Journal of Enology and Viticulture. 62: 298–311.

Havlin, J.L., Kissel, D.E., Maddux, L.D., Claassen, M.M., Long, J.H. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. *Soil Science Society of America Journal*. 54(2): 448-452.

He, X.-H., Critchley, C., Bledsoe, C. 2003. Nitrogen transfer within and between plants through common mycorrhizal networks (CMNs). *Critical Reviews in Plant Science*. 22: 531–-567.

Hector, A., Bagchi, R. 2007. Biodiversity na ecossystem multifuncionaity. *Nature*. 448: 188 – 190.

Helgason, T., Daniell, T.J., Husband, R., Fitter, A.H., Young, J.P.W. 1998. Ploughing up the wood-wide web? *Nature*. 394: 431–431.

Helgason, T. and Fitter, A. H. 2009. Natural selection and the evolutionary ecology of the arbuscular mycorrhizal fungi (Phylum Glomeromycota). *Journal of Experimental Botany*. 60(9): 2465-2480.

Hermans, C., Bourgis, F., Faucher, M., Strasser, R.J., Delrot, S., Verbruggen, N. 2005. Magnesium deficiency in sugar beets alters sugar partitioning and phloem loading in young mature leaves. *Planta*. 220: 541–549.

Hermawan, B., Bomke, A.A. 1997. Effects of winter cover crops and successive spring tillage on soil aggregation. *Soil and Tillage Research*. 44(1-2): 109-120.

Hickey, C.C., Hatch, T.A., Stallings, J., Wolf, T.K. 2016. Under-trellis cover crop and rootstock affect growth, yield components, and fruit composition of cabernet sauvignon. *American Journal of Enology and Viticulture*. 67(3): 281-295.

Hodge, A., Campbell, C.D., Fitter, A.H. 2001. An arbuscular mycorrhizal fungus accelerates decomposition and acquires nitrogen directly from organic material. *Nature*. 413: 297-299.

Holland, T.C., Bowen, P., Kokkoris, V., Úrbez-Torres, J.R. Hart, M. 2019. Does Inoculation with Arbuscular Mycorrhizal Fungi Reduce Trunk Disease in Grapevine Rootstocks? *Horticulturae*. 5(3): 61.

Hooks, C.R.R., Johnson, M.W. 2003. Impact of agricultural diversification on the insect community of cruciferous crops. Crop Protection. 22: 223-238.

Hosseinzadehtalaei, P., Tabari, H., and Willems, P. 2020. Climate change impact on short-duration extreme precipitation and intensity-duration-frequency curves over Europe. *Journal of Hydrology*. 590: 125249

Howarth, M.E., Thorncroft, C.D., Bosart, L.H. 2019. Changes in extreme precipitation in the Northeast United States: 1979–2014. *J. Hydrometeorol*. 20: 673–689

Igiehon, N. O. and Babalola, O. O. 2017. Biofertilizers and Sustainable Agriculture: Exploring Arbuscular Mycorrhizal Fungi. *Applied Microbiology Biotechnology*. 101: 4871–4881.

IJdo, M., Schtickzelle, N., Cranenbrouck, S., Declerck, S. 2010. Do arbuscular mycorrhizal fungi with contrasting life-history strategies differ in their responses to repeated defoliation?. *FEMS microbiology ecology*. 72(1): 114-122.

Ingels, C.A., Scow, K.M., Whisson, D.S., Drenovsky, R.E. 2005. Effects of cover crops on grapevines, yield, juice composition, soil microbial ecology, and gopher activity. *American Journal of Enology and Viticulture*. 56: 19-29.

Irvin, N.A., Scarratt, S.L., Wratten, S.D., Frampton, C.M., Chapman, R.B., Tylianakis, J.M. 2006. The effects of floral understoreys on parasitism of leafrollers (Lepidoptera: Tortricidae) on apples in New Zealand. *Agricultural and Forest Entomology*. 8(1): 25-34.

IVV database, 2020. Evolução da área total de vinha - Portugal. State of the Viticulture in Portugal. *Instituto da Vinha e do Vinho*.

Jackson, D.I., Lombard, P.B. 1993. Environmental and management practices affecting grape composition and wine quality-a review. *American journal of enology and viticulture.* 44(4): 409-430.

Jackson, L.E. 2000. Fates and losses of nitrogen from a nitrogen-15-labeled cover crop in an intensively managed vegetable system. *Soil Science Society of American Journal*. 64: 1404–1412.

Jakobsen, I. 1995. Transport of phosphorus and carbon in VA mycorrhizas. *In* Mycorrhiza Varma A, Hock B (eds). pp 297–324S. pringer-Verlag, Berlin.

Jansa, J., Mozafar, A., Anken, T., Ruh, R., Sanders, I.R., Frossard, E. 2002. Diversity and structure of AMF communities as affected by tillage in a temperate soil. *Mycorrhiza*. 12: 225–234

Jansa, J., Wiemken, A., Frossard, E. 2006. The effects of agricultural practices on arbuscular mycorrhizal fungi. *Geologial Society Special Publication.* 266: 89–115.

Jansa, J., Oberholzer, H.R., Egli, S. 2009. Environmental determinants of the arbuscular mycorrhizal fungal infectivity of Swiss agricultural soils. *European Journal of Soil Biology*. 45: 400–408.

Jasper, D.A., Abbott, L.K., Robson, A.D. 1989. Soil disturbance reduces the infectivity of external hyphae of vesicular- arbuscular mycorrhizal fungi. *New Phytologist*. 112: 93–99.

Javot, B., Pumplin, N., Harrison, A. 2007. Phosphate in the arbuscular mycorrhizal symbiosis: transport properties and regulatory roles. *Plant, Cell & Environment.* 30(3): 310–322.

Jeffries, P., Gianinazzi, S., Perotto, S., Turnau, K., Barea, J.M. 2003. The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. *Biology and Fertility of Soils.* 37: 1–16.

Jenkins, S., Waite, I.S., Blackburn, A., Husband, R., Rushton, S.P., Manning, D.C., O'Donnell, A.G. 2009. Actinobacterial community dynamics in long term managed grasslands. *Antonie Van Leeuwenhoek.* 95: 319–334.

Jeuffroy, M.H., Ney, B., Ourry, A. 2002. Integrated physiological and agronomic modelling of N capture and use within the plant. *Journal of Experimental Botany.* 50(370): 809–823.

Jezek, M. and Blatt, M. R. 2017. The membrane transport system of the guard cell and its integration for stomatal dynamics. *Plant Physiology.* 174: 487–519.

Johansen, A., Jakobsen, I., Jensen, E.S. 1992. Hyphal transport of 15N-labelled nitrogen by a vesicular—arbuscular mycorrhizal fungus and its effect on depletion of inorganic soil N. *New Phytologist*. 122(2): 281-288.

Johansen, A., Finlay, R.D., Olsson, P.A. 1996. Nitrogen metabolism of external hyphae of the arbuscular mycorrhizal fungus Glomus intraradices. *New Phytologist.* 133:705–712.

Jones, G.V., Davis, R.E. 2000. Climate influences on grapevine phenology, grape composition, and wine production and quality for Bordeaux, France. *American journal of enology and viticulture*. 51(3): 249-261.

Jordan, L.M., Björkman, T., Heuvel, J.E.V. 2016. Annual under-vine cover crops did not impact vine growth or fruit composition of mature cool-climate 'Riesling' grapevines. *HortTechnology*. 26(1): 36-45.

Kabir, Z., O'halloran, I.P., Fyles, J.W., Hamel, C. 1997. Seasonal changes of arbuscular mycorrhizal fungi as affected by tillage practices and fertilization: hyphal density and mycorrhizal root colonization. *Plant and Soil.* 192(2): 285-*293.*

Kabir, Z., Koide, R.T., 2000. The effect of dandelion or a cover crop on mycorrhiza inoculum potential, soil aggregation and yield of maize. *Agriculture, Ecosystems & Environment*. 78: 167–174.

Kabir, Z. 2005. Tillage or no-tillage: impact on mycorrhizae. Canadian Journal of Plant Science. 85(1): 23–29.

Kalayu, Girmay. 2019. Phosphate Solubilizing Microorganisms: Promising Approach as Biofertilizers. *International Journal of Agronomy.* 2019: 1–7.

Kapoor, R., Evelin, H., Mathur, P., Giri, B. 2013. Arbuscular mycorrhiza: approaches for abiotic stress tolerance in crop plants for sustainable agriculture. *In* Plant acclimation to environmental stress (pp. 359-401). Springer, New York, NY.

Karagiannidis N., Velemis D., Stavropoulos N. 1997. Root colonization and spore population by VA mycorrhizal fungi in four grapevine rootstocks. *Vitis*. 36: 57–60.

Karandashov, V., Bucher, M. 2005. Symbiotic phosphate transport in arbuscular mycorrhizas. *Trends in Plant Science*. 10: 22–29.

Karl, A., Merwin, I.A., Brown, M.G., Hervieux, R.A., Heuvel, J.E.V. 2016. Impact of undervine management on vine growth, yield, fruit composition, and wine sensory analyses in cabernet franc. *American Journal of Enology and Viticulture*. 67(3): 269-280.

Kaspar, T.C., Radke, J.K., Laflen, J.M., 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff and erosion*. Journal of Soil Water Conservation*. 56: 160–164.

Kaspar, T.C., and J.W. Singer. 2011. The use of cover crops to manage soil*. In* , Soil management: Building a stable base for agriculture. J.L. Hatfield, and T.J. Sauer (eds) p. 321–337. *American Society Agronomy* and Soil Science Society of Americe, Madison.

Keller, M. 2010. Managing grapevines to optimise fruit development in a challenging environment: a climate change primer for viticulturist. *Australian Journal of Grape and Wine Research.* 16: 56–69.

Khade, S.W., Rodrigues, B.F. 2009. Applications of arbuscular mycorrhizal fungi in agroecosystems. *Tropical and Subtropical Agroecosystems*. 10(3): 337-354.

Khalil, H.A. 2013. Influence of Vesicular-arbuscula Mycorrhizal Fungi (Glomus spp.) on the Response of Grapevines Rootstocks to Salt Stress. *Asian Journal of Crop Science.*

Kohler, J., Caravaca, F., Carrasco, L., Roldan, A. 2006. Contribution of Pseudomonas mendocina and Glomus intraradices to aggregate stabilization and promotion of biological fertility in rhizosphere soil of lettuce plants under field conditions. *Soil Use and Management*. 22(3): 298-304.

Kim, N., Zabaloy, M.C., Guan, K., Villamil, M.B. 2020. Do cover crops benefit soil microbiome? A meta-analysis of current research. *Soil Biology and Biochemistry.* 142: 107701.

King, A.E., Hofmockel, K.S., 2017. Diversified cropping systems support greater microbial cycling and retention of carbon and nitrogen. *Agriculture, Ecosystems & Environment*. 240: 66–76.

Kivlin, S.N., Hawkes C.V., Treseder K.K. 2011. Global Diversity and Distribution of Arbuscular Mycorrhizal Fungi. *Soil Biology & Biochemistry*. 43: 2294-2303

Klironomos, J.N., Hart, M.M. 2002. Colonization of roots by arbuscular mycorrhizal fungi using different sources of inoculum. *Mycorrhiza.* 12: 181–184.

Kocira, A., Staniak, M.,Tomaszewska, M., Kornas, R., Cymerman, J., Panasiewicz, K., Lipińska, H. 2020. Legume Cover Crops as One of the Elements of Strategic Weed Management and Soil Quality Improvement. A Review. *Agriculture*. 10(9): 394.

Kochian, L.V. 2000. Molecular Physiology of Mineral Nutrients Acquisition, Transports, and Utilization. *In* Biochemistry and molecular biology of plants. Buchanan BB, Gruissem W, Jones RL (eds). Pp. 1204–1249. American Society of Plant Biologists, Rockville, MD, USA.

Köhl, L., Lukasiewicz, C. E., Van der Heijden, M.G.A., 2016. Establishment and effectiveness of inoculated arbuscular mycorrhizal fungi in agricultural soils*. Plant Cell and Environment*. 39(1): 136-146.

Kornberg, A., Rao, N.N., Ault-Riche, D. 1999. Inorganic polyphosphate: a molecule of many functions. *Annual Review of Biochemistry.* 68: 89–125.

Kosuta, S., Chabaud, M., Lougnon, G., Gough, C., Dénaríe, J., Barker, D.G., Bécard, G. 2003. A diffusible factor from arbuscular mycorrhizal fungi induces symbiosis-specific *MtENOD11* expression in roots of *Medicago truncatula*. *Plant Physiology.* 131: 952–62.

Kraut-Cohen, J., Zolti, A., Shaltiel-Harpaz, L., Argaman, E., Rabinovich, R., Green, S.J., Minz, D. 2020. Effects of tillage practices on soil microbiome and agricultural parameters. *Science of the Total Environment.* 705: 135791.

Krishna, H., Singh, S.K., Sharma, R.R., Khawale, R.N., Grover, M., Patel, V.B. 2005. Biochemical changes in micropropagated grape (Vitis vinifera L.) plantlets due to arbuscular-mycorrhizal fungi (AMF) inoculation during ex vitro acclimatization. *Scientia Horticulturae*. 106(4): 554-567.

Krishna, H., Singh, S.K., Minakshi, Patel, V.B., Khawale, R.N., Deshmukh, P.S., Jindal, P.C. 2006. Arbuscular-mycorrhizal fungi alleviate transplantation shock in micropropagated grapevine (Vitis vinifera L.). *The Journal of Horticultural Science and Biotechnology*. 81(2): 259-263.

Kubikova, E., Moore, J.L., Ownlew, B.H., Mullen, M.D., Augé, R.M. 2001. Mycorrhizal impact on osmotic adjustment in *Ocimum basilicum* during a lethal drying episode. *Plant Physiology.* 158: 1227–1230.

Kuhn, H., Kuster, H., Requena, N. 2010. Membrane steroid-binding protein 1 induced by a diffusible fungal signal is critical for mycorrhization in *Medicago truncatula*. *New Phytologist.* 185: 716–33.

Kuimei, Q., Liping, W., Ningning, Y. 2012. Effects of AMF on soil enzyme activity and carbon sequestration capacity in reclaimed mine soil. *International Journal of Mining Science and Technology.* 22: 553-557.

Kumar, S., Sharma, A.K., Rawat, S.S., Jain, D.K., Ghosh, S. 2013. Use of pesticides in agriculture and livestock animals and its impact on environment of India. *Asian Journal of Environmental Science*. 8(1): 51-57.

Landis, D.A., Wratten, S.D., Gurr, G.M. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual review of entomology*. 45(1): 175-201.

Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J., Garnier, J. 2014. 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland. *Environmental Research Letters*. 9: 105011.

Laudicina, V.A.; Palazzolo, E.; Catania, P.; Vallone, M.; García, A.D.; Badalucco, L. 2016. Soil quality indicators as affected by shallow tillage in a vineyard grown in a semiarid Mediterranean environment. *Land Degradation and Development*. 28(3): 1038-1046.

Latef, A.A.H.A., Hashem, A., Rasool, S., Abd_Allah, E.F., Alqarawi, A.A., Egamberdieva, D., Jan, S., Anjum, N.A., Ahmad, P. 2016. Arbuscular mycorrhizal symbiosis and abiotic stress in plants: a review. *Journal of plant biology*. 59(5): 407-426.

Lavelle, P., Dugdale, R., Scholes, R., Berhe, A. A., Carpenter, E., Codispoti, L., Izac, A.M., Lemoalle, J., Luizao, F., Scholes, M., Tréguer, P., Ward, B. 2005. Nutrient cycling. In Ecosystems and Human Well-Being: Current State and Trends: Findings of the Condition and Trends Working Group, Island Press, Washington, Covelo, London.

Le Bissonais, Y., Lecomte, V., Cerdan, O. 2004. Grass strip effects on runoff and soil loss. *Agronomie*. 24: 129–136.

Leake, J., Johnson, D., Donnelly, D., Muckle, G., Boddy, L., Read, D. 2004. Networks of power and influence: the role of mycorrhizal mycelium in controlling plant communities and agroecosystem functioning. *Canadian Journal of Botany*. 82(8): 1016-1045.

Leifheit, E.F., Veresoglou, S.D., Lehmann, A., Morris, E.K., Rillig, M.C. 2014. Multiple factors influence the role of arbuscular mycorrhizal fungi in soil aggregation – a meta-analysis. *Plant and Soil.* 374: 523–537.

Lendzemo, V.W., Kuyper, T.W., Matusova, R., Bouwmeester, H.J., Ast, A.V. 2007. Colonization by arbuscular mycorrhizal fungi of sorghum leads to reduced germination and subsequent attachment and emergence of Striga hermonthica. *Plant signaling & behavior*. 2(1): 58-62.

Leys, A., Govers, G., Gillijns, K., Poesen, J. 2007. Conservation tillage on loamy soils: explaining the variability in interrill runoff and erosion reduction. *European Journal of Soil Science*. 58: 1425–1436.

Li, H.Y., Yang, G.D., Shu, H.R., Yang, Y.T., Ye, B.X., Nishida, I., Zheng, C.C. 2006. Colonization by the arbuscular mycorrhizal fungus Glomus versiforme induces a defense response against the root-knot nematode Meloidogyne incognita in the grapevine (Vitis amurensis Rupr.), which includes transcriptional activation of the class III chitinase gene VCH3. *Plant and cell physiology*. 47(1): 154-163.

Lichtenberg, E. 2004. Cost-responsiveness of conservation practice adoption: A revealed preference approach. *Journal of Agricultural and Resource Economics*. 420-435.

Likar, M., Hančević, K., Radić, T., Regvar, M. 2013. Distribution and diversity of arbuscular mycorrhizal fungi in grapevines from production vineyards along the eastern Adriatic coast. *Mycorrhiza*. 23(3): 209-219.

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.

Linares, R., Fuente, M., Junquera, P., Baeza, P. 2007. Response of a Merlot vineyard to several soil management practices in a mediterranean environment. *In* Proceedings XV GESCO International Symposium. Vol. 1, pp. 371-377.

Lopes, C., Monteiro, A., Rückert, F.E., Gruber, B., Steinberg, B., Schultz, H.R. 2004. Transpiration of grapevines and co-habitating cover crop and weed species in a vineyard. A "snapshot" at diurnal trends. *Vitis - Journal of Grapevine Research.* 43(3): 111-117.

Lopes, C. M., Monteiro, A., Machado, J. P., Fernandes, N., & Araújo, A. 2008. Cover cropping in a sloping non-irrigated vineyard: II—Effects on vegetative growth, yield, berry and wine quality of "Cabernet Sauvignon" grapevines. *Ciência e Técnica Vitivinícola.* 23(1): 37-43.

Lopes, C.M., Santos, T.P., Monteiro, A., Rodrigues, M.L., Costa, J.M., Chaves, M.M. 2011. Combining cover cropping with deficit irrigation in a Mediterranean low vigor vineyard. *Scientia Horticulturae.* 129(4): 603-612.

Lopes, C.M. 2016. Cover crops competition for water in vineyards: case studies in mediterranean terroirs. In Proceedings 11th Int. Terroir Congress. Jones, G. and Doran, N.(eds.), pp. 117-123. Southern Oregon University, Ashland, USA.

Lopez-Millan AF, Sagardoy, R., Solanas, M., Abadía, A., Abadí, J. 2009. Cadmium toxicity in Tomato (Lycopersicon esculentum) plants grown in hydroponics. *Environmental and Experimental Botany*. 65(2-3): 376–385.

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.

Lovisolo, C., Lavoie-Lamoureux, A., Tramontini, S., Ferrandino, A. 2016. Grapevine adaptations to water stress: new perspectives about soil/plant interactions. *Theoretical and Experimental Plant Physiology*. 28(1): 53-66.

Lumini, E., Orgiazzi, A., Borriello, R., Bonfante, P., Bianciotto, V. 2010 Disclosing arbuscular mycorrhizal fungal biodiversity in soil through a land-use gradient using a pyrosequencing approach. *Environmental microbiology.* 12(8): 2165-2179.

Luttikholt, L.W. 2007. Principles of organic agriculture as formulated by the International Federation of Organic Agriculture Movements. *NJAS-Wageningen Journal of Life Sciences*. 54(4): 347-360.

Lynch, J.P. 2007. Roots of the Second Green Revolution. *Australian Journal of Botany*. 55(5): 493.

Magurno, F., Balestrini, R., Lumini, E., Bianciotto, V. 2010. Outside and Inside Grapevine Roots: Arbuscular Mycorrhizal Fungal Communities in a ' Nebbiolo '. *Quaderni di Scieze Viticole ed Enologiche Univ. Torino.* 31: 91-95.

Malik, R.K., Green, T.H., Brown, G.F., Mays, D., 2000. Use of cover crops in short rotation hardwood plantations to control erosion. *Biomass Bioenergy.* 18: 479–487.

Mallik, M.A.B., Williams, R.D. 2005. Allelopathic growth stimulation of plants and microorganisms. *Allelopathy Journal.* 16(2): 175.

Mandelli, F., Tonietto, J., Hasenack, H., Weber, E. 2005. ZONEAMENTO CLIMÁTICO PARA A PRODUÇÃO DE UVAS PARA VINHOS DE QUALIDADE Índice Heliotérmico para o Estado do Rio Grande do Sul. *In* Congresso Brasileiro de Agrometeorologia. 14

Marschner, H., Dell, B. 1994. Nutrient uptake in mycorrhizal symbiosis. *Plant and Soil*. 159: 89–102.

McClelland, S.C., Paustian, K., Schipanski, M.E. 2021. Management of cover crops in temperate climates influences soil organic carbon stocks: a meta-analysis. *Ecological Applications*. 31(3): e02278.

McGourty, G.T., J.P. Reganold. 2005. Managing vineyard soil organic matter with cover crops. *In* Proceedings of the Soil E nvironment and Vine Mineral Nutrition Symposium. Christensen, P. and Smart, D.R. (eds.), pp. 145-151. American Society for Enology and Viticulture, Davis.

McGovern, P., et al. 2017. Early neolithic wine of Geogia in the South Cascasus. *Proceedings of the National Academy of Sciences*. 114(48): E10309-E10318.

Menge, J.A., Munnecke, D.E., Johnson, E.L.V., Carnes, D.W. 1978. Dosage response of the vesicular-arbuscular mycorrhizal fungi Glomus fasciculatus and G. constrictus to methyl bromide. *Phytopathology.* 68: 1368–1372.

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.

Miransari, M. 2011. Hyperaccumulators, arbuscular mycorrhizal fungi and stress of heavy metals. *Biotechnology Advances*. 29(6): 645-653.

Monteiro, A., Lopes, C.M. 2007. Influence of cover crop on water use and performance of vineyard in Mediterranean Portugal. *Agriculture, ecosystems & environment*. 121(4): 336-342.

Moore, D., Robson, G.D., Trinci, A.PJ. 2020. *In* 21st Century Guidebook to Fungi. Types of Mycorrhiza. 356-367.

Morgan, R.P.C., 2005. Soil erosion and conservation (3rd Ed). Blackwell Science Ltd, Oxford.

Morin, E., et al. 2019. Comparative genomics of *Rhizophagus irregularis*, *R. cerebriforme, R. diaphanus* and *Gigaspora rosea* highlights specific genetic features in Glomeromycotina. *New Phytologist*. 222(3): 1584-1598.

Morlat, R. 1987. Influence du mode d'entretien du sol sur l'alimentation en eau de la vigne en Anjou, Conséquences agronomiques. *Agronomie*. 7: 183–191.

Morlat, R., Jacquet, A. 2003. Grapevine root system and soil characteristics in a vineyard maintained long-term with or without interrow sward. American Journal of Enology and Viticulture. 54: 1-17.

Morte, A., Lovisolo, C., Schubert, A. 2000. Effect of drought stress on growth and water relations of the mycorrhizal association *Helianthemum almeriense–Terfezia claveryi. Mycorrhiza.* 10: 115–119.

Morvan, X., Naisse, C., Malam Issa, O., Desprats, J. F., Combaud, 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.

Moulis, I. 1994. L'enherbement des vignobles méditerranéens: importance de la compétition hydrique vigne/culture intercalaire herbacée en vue d'un maîtrise de la production viticole. PhD thesis. ENSA-M, Montpellier, 106 pp.

Munkvold, L., Kjoller, R., Vestberg, M., Rosendahl, S., Jakobsen, I. 2004. High funtional diversity species of arbuscular mycorrhizal fungi. *New phytologist*. 164(2): 357 – 364.

Munns, R. 2002. Comparative physiology of salt and water stress. Plant Cell & Environment. 2: 239-250

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 Mediterranean climate. *Agriculture, Ecosystems & Environment.* 237: 203-212.

Nascente, A.S., Li, Y.C., Crusciol, C.A.C. 2013. Cover crops and no-till effects on physical fractions of soil organic matter. *Soil and Tillage Research.* 130: 52-57.

National Geographic Society, 2019. Atmosphere. National Geographic Encyclopaedia website. https://www.nationalgeographic.org/encyclopedia/atmosphere/

Nazrala, J.J.B. 2008. Influence of soil management and plant cover on the microclimate of the vine canopy, the composition of the grape and the wine. *Journal of the Faculty of Agricultural Sciences*. 40(1): 85-104.

Neumann, P.A., Matzarakis, A. 2011. Viticulture in southwest Germany under climate change conditions. *Climate research*. 47(3): 161-169.

Nicolás, E., Maestre-Valero, J. F., Alarcón, J. J., Pedrero, F., Vicente-Sánchez, J., Bernabé, A., Gómez-Montiel, J., Hernández, J.A., Fernández, F. 2015. Effectiveness and persistence of arbuscular mycorrhizal fungi on the physiology, nutrient uptake and yield of Crimson seedless grapevine. *The Journal of Agricultural Science*. 153(6): 1084-1096.

Nogales, A., Aquirreolea, J., Santa María, E., Camprubí, A., Calvet, C. 2009. Response of mycorrhizal grapevine to Armillaria mellea inoculation: disease development and polyamines. Plan Soil. 317: 177-187.

Nogales, A., Luque, J., Estaún, V., Camprubí, A., Garcia-Figueres, F., Calvet, C. 2009. Differential growth of mycorrhizal field-inoculated grapevine rootstocks in two replant soils. *American Journal of Enology and Viticulture.* 60(4): 484-489.

Nogales, A., Aguirreolea, J., Santa María, E., Camprubí, A., Calvet, C. 2009. Response of mycorrhizal grapevine to Armillaria mellea inoculation: disease development and polyamines. *Plant and Soil*. 317(1): 177-187.

Nogales, A., Camprubí, A., Estaún, V., Calvet, C. 2008. Mycorrhizal inoculation of grapevines in replant soils: improved field application and plant performance. *Mycorrhiza application in sustainable agriculture and natural systems. COST Action.* 870: 12-15.

Nogales, A., Santos, E.S., Abreu, M.M., Arán, D., Victorino, G., Pereira, H.S., Lopes, C.M., Viegas, W. 2019. Mycorrhizal Inoculation Differentially Affects Grapevine's Performance in Copper Contaminated and Non-contaminated Soils. *Frontiers in Plant Science.* 9: 1906.

Nogales, A., Rottier, E.,Campos, C.,Victorino, G., Costa, J.M., Coito, J.L., Pereira, H.S., Viegas, W., Lopes, C. 2021. The effects of field inoculation of arbuscular mycorrhizal fungi through rye donor plants on grapevine performance and soil properties. *Agriculture, Ecosystems and Environment*. 313: 107369.

Novara, A., Gristina, 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.

Novara, A., Pisciotta, A., Minacapilli, M., Maltese, A., Capodici, F., Cerdà, A., Gristina, L. 2018. The impact of soil erosion on soil fertility and vine vigor. A multidisciplinary approach based on field, laboratory and remote sensing approaches. *Science of the Total Environment*. 622: 474–480

Obi, M.E., 1999. The physical and chemical responses of a degraded sandy clay loam soil to cover crops in southern Nigeria. *Plant Soil*. 211: 165–172.

Oehl, F., Koch, B. 2018. Diversity of arbuscular mycorrhizal fungi in no-till and conventionally tilled vineyards. *Journal of Applied Botany and Food Quality*. 91: 56-60.

OIV, 2019. State of the Viticulture world market. *International Organization of Vine and Wine*.

Oldeman, L.R., 1994. The global extent of land degradation. *In* Land Resilience and Sustainable Land Use. Greenland, D.J., Szabolcs, I. (Eds). pp. 99–118. Wallingford, UK.

Öpik, M., Moora, M., Liira, J., Zobel, M., 2006. Composition of Coot-Colonizing Arbuscular Mycorrhizal Fungal Communities in Different Ecosystems Around the Globe. *Journal of Ecology*. 94: 778-790.

Ortas, I. 2012. The effect of mycorrhizal fungal inoculation on plant yield, nutrient uptake and inoculation effectiveness under long-term field conditions. *Field Crops Research.* 125: 35–48.

Ouziad, F., Hildebrandt, U., Schmelzer, E., and Bothe, H. 2005. Differential gene expressions in arbuscular mycorrhizal-colonized tomato grown under heavy metal stress. *Journal Plant Physiology.* 162: 634–649.

Ozdemir, G., Akpinar, Ç, Sabir, A., Bilir, H., Tangolar, S., Ortas, I. 2010. Effect of Inoculation with Mycorrhizal Fungi on Growth and Nutrient Uptake of Grapevine Genotypes (Vitis spp.). *European Journal of Horticultural Science*. 75(3): 103-110.

Palliotti, A., Tombesi, S., Silvestroni, O., Lanari, V., Gatti, M., Poni, S. 2014. Changes in vineyard establishment and canopy management urged by earlier climate-related grape ripening: A review. *Scientia Horticulturae*. 178: 43-54.

Pandey, R., Singh, B., and Nair, T.V.R. 2005. Impact of arbuscular–mycorrhizal fungi on phosphorus efficiency of wheat, rye, and triticale. Journal Plant Nutrition. 28(10): 1867–1876.

Pardini, A., Faiello, C., Longhi, F., Mancuso, S., Snowball, R. 2002. Cover crop species and their management in vineyards and olive groves. *Advances in Horticultural Science.* 16 (3-4): 225-234.

Parkin, T.B., Kaspar, T.C., Singer, J.W., 2006. Cover crop effects on the fate of N following soil application of swine manure. Plant Soil. 289: 141–152.

Penfold, C., Weckert, M., Nordblom, T., Howie, J., Norton, M. 2018. Development of a low-input under-vine floor management system which improves profitability without compromising yield or quality.: FINAL REPORT to WINE AUSTRALIA, Project Number: UA 1303.

Pérez-Álvarez, E. P., García-Escudero, E., Peregrina, F. 2015. 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.

Perkons U, Kautz T, Uteau D, Peth S, Geier V, Thomas K, Lütke Holz K, Athmann M, Pude R and Köpke U. 2014. Root-length densities of various annual crops following crops with contrasting root systems. Soil and Tillage Research. 137: 50-57.

Perry, D.A. 1995. Self-organizing systems across scales. *TREE.* 10: 241–245.

Pianka, E.R. 1970. On r and K selection. *The American Naturalist*. 104: 592–597.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science*. 267: 1117–1123.

Poeplau, C., and A. Don. 2015. Carbon sequestration in agricultural soils via cultivation of cover crops: A meta-analysis. Agricuture, Ecosystem and Environment. 200: 33–41.

Ponti, L., Altieri, M.A., Gutierrez, A.P. 2007. Effects of crop diversification levels and fertilization regimes on abundance of Brevicoryne brassicae (L.) and its parasitization by Diaeretiella rapae (M'Intosh) in broccoli. *Agricultural and Forest Entomology*. 9(3): 209-214.

Popescu, G.C. 2016. Arbuscular Mycorrhizal Fungi – an essential tool to sustainable vineyard development: a review. *Current Trends in Natural Sciences.* 5(10): 107-116.

Pou, A., Gulías, J., Moreno, M., Tomàs, 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. *Oeno One*. 45(4): 223-234.

Pozo, M.J., Cordier, C., Dumas, E., Gianinazzi, S., Barea, J.M., Azcón-Aguilar, C. 2002. Localized vs systemic effect of arbuscular mycorrhizal fungi on defence responses to Phytophthora infection on tomato plants. Journal of Experiment Botany. 53: 525–534

Prasifka, J.R., Schmidt, N.P., Kohler, K.A., O'neal, M.E., Hellmich, R.L., Singer, J.W. 2006. Effects of living mulches on predator abundance and sentinel prey in a corn–soybean–forage rotation. *Environmental Entomology*. 35(5): 1423-1431.

Punamiya, P., Datta, R., Sarkar, D., Barber, S., Patel, M., Da, P. 2010. Symbiotic role of *Glomus mosseae* in phytoextraction of lead in vetiver grass *Chrysopogon zizanioides* L. *Journal of Hazardous Materias.* 177: 465–474.

Qiu, B. 2006. Phylogenetic distribution and evolution of mycorrhizas in land plants. *Mycorrhiza*. 16: 299-363.

Quecedo, I.V., Gurruchaga, M.J.I., Ugalde, O.F., Urrutia, I., Martín, A.E., Miquel, P.B. 2012. Soil quality evaluation following the implementation of permanent cover crops in semi-arid vineyards. Organic matter, physical and biological soil properties. *Spanish journal of agricultural research*. 4: 1121-1132.

Quemada, M., M. Baranski, M.N.J. Nobel-de Lange, A. Vallejo, J.M. Cooper. 2013. Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yield. Agriculture, Ecosystem & Environment. 174: 1–10.

Radić, T., Hančević, K., Likar, M., Protega, I., Jug-Dujaković, M., Bogdanović, I. 2012. Neighbouring weeds influence the formation of arbuscular mycorrhiza in grapevine. *Symbiosis.* 56(3): 111-120.

Redecker, D., Kodner, R., Graham, L.E. 2000. Glomalean Fungi from the Ordovician. *Science.* 289: 1920–1921

Redecker, D., Schüßler, A., Stockinger, H., Stürmer, S. L., Morton, J. B., Walker, C. 2013. An evidence-based consensus for the classification of arbuscular mycorrhizal fungi (Glomeromycota). *Mycorrhiza*. 23(7): 515-531.

Reisch, B.I., Owens, C.L., Cousins, P.S. 2012. Grape. *In* Fruit breeding. pp. 225-262. Springer, Boston, MA.

Remy, W., Taylor, T.N., Hass, H., Kerp, H. 1994. Four hundred-million-year-old vesicular arbuscular mycorrhizae. *Proceedings of the National Academy of Sciences*. 91(25): 11841-11843.

Reynier, A., 2004. Manual de Viticultura. 3rd edition, Publicacoes Europa-America, Portugal.

Rillig, M. C., Mummey, D. L. 2006. Mycorrhizas and soil structure. *New Phytologist.* 171: 41-53.

Rivera-Becerril, F., Calantzis, C., Turnau, K., Caussanel, J.-P., Belimov, A., Gianinazzi, S., Strasser, R. J., Gianinazzzi-Pearson, V. 2002. Cadmium accumulation and buffering of cadmium-induced stress by arbuscular in three Pisum sativum L. genotypes. *Journal of Experimental Botany*. 53(371): 1177–1185.

Rocha, I., Ma, Y., Souza-Alonso, P., Vosátka, M., Freitas, H., Oliveira, R. S. 2019. Seed coating: a tool for delivering beneficial microbes to agricultural crops. *Frontiers in Plant Science*. 10: 1357.

Rodriguez-Lovelle, B., Soyer, J., Molot, C., 2000. Incidence of permanent grass cover on grapevine phenological evolution and grape berry ripening. *In* Bravdo, B.A., (ed.), V. International Symposium on Grape-vine Physiology. 526: 241-248.

Rose, M.T., Cavagnaro, T.R., Scanlan, C.A., Rose, T.J., Vancov, T., Kimber, S., Kennedy, I.R., Kookana, R.S., Van Zwieten, L. 2016. Impact of Herbicides on Soil Biology and Function. *Advances in Agronomy.* 136: 133-220.

Rouphael, Y., Franken, P., Schneider, C., Schwarz, D., Giovannetti, M., Agnolucci, M., De Pescale, S., Bonini, P., Colla, G. 2015. Arbuscular mycorrhizal fungi act as biostimulants in horticultural crops. *Scientia Horticulturae.* 196: 91-108.

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.

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.

Ryan, M.H., Angus, J.F. 2003. Arbuscular mycorrhizae in wheat and field pea crops on a low P soil: increased Zn-uptake but no increase in P-uptake or yield. *Plant and Soil.* 250(2): 225-239.

Ryder, M.H., Fares, A., 2008. Evaluating cover crops (sudex, sunn hemp, oats) for use as vegetative filters to control sediment and nutrient loading from agricultural runoff in a Hawaiian watershed. *Journal of the American Water Resource.* 44: 640–653.

Sahu N., Vasu D., Sahu A., Lal N., Singh S.K. 2017. Strength of Microbes in Nutrient Cycling: A Key to Soil Health. *In* Agriculturally Important Microbes for Sustainable Agriculture. Meena V., Mishra P., Bisht J., Pattanayak A. (eds). Springer, Singapore.

Salazar, D., and P. Melgarejo. 2005. Manejo del suelo. *In* Viticultura. Técnicas de cultivo de la vid, calidad de la uva y atributos de los vinos. A. Madrid Vicente (ed.), pp. 201-208. Mundi-Prensa, Madrid.

Salome, C.; Coll, P.; Lardo, E.; Villenave, C.; Blanchart, E.; Hinsinger, P.; Marsden, C.; Le Cadre, E. 2014. Relevance of use-invariant soil properties to assess soil quality of vulnerable ecosystems: The case of Mediterranean vineyards. Ecological Indicatord. 43: 83–93.

Sánchez-Blanco, M. J., Ferrández, T., Morales, M. A., Morte, A., Alarcón, J. J. 2004. Variations in water status, gas exchange, and growth in Rosmarinus officinalis plants infected with Glomus deserticola under drought conditions. *Journal of Plant Physiology.* 16: 675–682.

Sánchez-Romera, B., Ruiz-Lozano, J.M., Zamarreño, Á.M., García-Mina, J.M., Aroca, R. 2016. Arbuscular mycorrhizal symbiosis and methyl jasmonate avoid the inhibition of root hydraulic conductivity caused by drought. *Mycorrhiza.* 26(2): 111-122.

Santos, J.A., Malheiro, A.C., Karremann, M.K., Pinto, J.G. 2011. Statistical modelling of grapevine yield in the Port Wine region under present and future climate conditions. *International Journal of Biometeorology.* 55(2): 119-131.

Sato, T., Ezawa, T., Cheng, W., Tawaraya, K. 2015. Release of acid phosphatase from extraradical hyphae of arbuscular mycorrhizal fungus Rhizophagus clarus. *Journal of Plant Nutrition and Soil Science.* 61:269–274.

Savci, S. 2012. Investigation of effect of chemical fertilizers on environment. *Apcbee Procedia.* 1: 287-292.

Sawers, R. J. H., Yang, SY., Gutjahr, C., Paszkowski, U. 2008. Chapter 2: The Molecular Components of Nutrient Exchange in Arbuscular Mycorrhizal Interactions. *In* Mycorrhizae: Sustainable Agriculture and Forestry. Siddiqui Z.A., Akhtar M.S., Futai K. (eds). Springer, Dordrecht. 37-59.

Schliemann W, Ammer C, Strack D. 2008. Metabolite profiling of mycorrhizal roots of Medicago truncatula. Phytochem 69: 112–146.

Schreiner, R.P., Mihara, K.L., McDaniel, H., Bethlenfalvay, G.J., 1997. Mycorrhizal fungi influence plant and soil functions and interactions. *Plant Soil*. 188: 199–209.

Schreiner, R.P. and Linderman, R.G. 2005. Mycorrhizal Colonization in Dryland Vineyards of the Willamette Valley, Oregon. *Small Fruits Review*. 4(3): 41-55.

Schreiner, R.P. 2005. Mycorrhizas and mineral acquisition in grapevines. In *Proceedings of the soil environment and vine mineral nutrition symposium* (pp. 49-60). American Society for Enology and Viticulture.

Schreiner, R P. 2007. Effects of native and nonnative arbuscular mycorrhizal fungi on growth and nutrient uptake of 'Pinot noir'(Vitis vinifera L.) in two soils with contrasting levels of phosphorus. *Applied soil ecology.* 36(2-3): 205-215.

Schreiner, R.P., Mihara, K.L. 2009. The diversity of arbuscular mycorrhizal fungi amplified from grapevine roots (Vitis vinifera L.) in Oregon vineyards is seasonally stable and influenced by soil and vine age. *Mycologia*. 101(5): 599-611.

Schübler, A., Schwarzott, D., Walker, C. 2001. A new fungal phylum, the Glomeromycota: phylogeny and evolution. *Mycological Research*. 105(12): 1413-1421.

Schultz, H.R., Stoll, M. 2010. Some critical issues in environmental physiology of grapevines: future challenges and current limitations. *Australian Journal of Grape and Wine Research*. 16: 4-24.

Seeram, N. P. 2008. Berry fruits: compositional elements, biochemical activities, and the impact of their intake on human health, performance, and disease. *Journal of Agricultural and Food Chemistry*. 56(3): 627-629.

Selosse, M.A., Le Tacon, F. 1998. The land flora: a phototroph-fungus partnership? Trends in Ecology & Evolution. The Equipe de Microbiologie Forestière, INRA Nancy, Champenoux, France. *TREE.* 13: 15–20.

Serrano, R., Culianz-Macia, F., Moreno, V., 1999. Genetic engineering of salt and drought tolerance with yeast regulatory genes. *Scientia Horticulturae*. 78: 261-269.

Shani, U., Ben-Gal, A. 2005. Long-term response of grapevines to salinity: osmotic effects and ion toxicity. *American Journal of Enology and Viticulture.* 56: 148-154.

Shannon, M.C., Grieve, C.M. 1998. Tolerance of vegetable crops to salinity. Scientia Horticulturae. 78: 5–38.

Sharley, D.J., Hoffmann, A.A., Thomson, L.J. 2008. Effects of soil tillage on beneficial invertebrates within the vineyard. *Agricultural and Forest Entomology*.

Shen, J., Yuan, L., Zhang, J., Li, H., Bai, Z., Chen, X., Zhang, F., Zhang, F. 2011. Phosphorus dynamics: from soil to plant. *Plant physiology*. 156(3): 997-1005.

Sheng, M., Tang, M., Zhang, F., and Huang, Y. 2011. Influence of arbuscular mycorrhiza on organic solutes in maize leaves under salt stress. *Mycorrhiza.* 21: 423–430.

Shrestha, A., Kurtural, S.K., Fidelibus, M.W., Dervishian, G., Konduru, S., 2013. Efficacy and cost of cultivators, steam, or an organic herbicide for weed control in organic vineyards in the San Joaquin Valley of California. *HortTechnology*. 23(1): 99–108.

Sieverding, E., Friedrichsen, J., Suden, W. 1991. Vesicular-arbuscular mycorrhiza management in tropical agrosystems. *Sonderpublikation der GTZ (Germany)*.

Six, J.K., Elliot, E.T., Paustian, K., 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Science Society of American Journal*. 63: 1350–1358.

Smart, R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. A review. *American Journal of Enology and Viticulture.* 36: 230-239.

Smart, R., Robinson, M. 1991. *In* Sunlight into wine: a handbook for winegrape canopy management. Winetitles, SA, Australia

Smil, V. 2004. *In* Enriching the earth: Fritz Haber, Carl Bosch, and the transformation of world food production. MIT press.

Smith, R., Bettiga, L., Cahn, M., Baumgartner, K., Jackson, L., Bensen, T. 2008. Vineyard floor management affects soil, plant nutrition, and grape yield and quality.*California agriculture.* 62(4): 184-190.

Smith, S.E., Read, D.J. 2008. *In* Mycorrhizal symbiosis (3rd ed). Academic Press, London

Smith, S.E., Smith, F.A. 2011. Roles of arbuscular mycorrhizas in plant nutrition and growth: new paradigms from cellular to ecosystem scales. *Annual Review of Plant Biology.* 62: 227–50.

Snapp, S.S., Swinton, S.M., Labarta, R., Mutch, D., Black, J.R., Leep, R., Nyiraneza, J., O'neil, K. 2005. Evaluating cover crops for benefits, costs and performance within cropping system niches. *Agronomy journal*. 97(1): 322-332.

Sofia, G.; Tarolli, P. 2017. Hydrological response to ~30 years of agricultural surface water management. *Land*. 6(1): 3.

Solaiman, M.Z., Ezawa, T., Kojima, T., Saito, M. 1999. Polyphosphates in intraradical and extraradical hyphae of an arbuscular mycorrhizal fungus, *Gigaspora margarita*. *Applied and Environmental Microbiology.* 65: 5604–5606.

Soti, P.G., Rugg, S., Racelis, A. 2016. Potential of Cover Crops in Promoting Mycorrhizal Diversity and Soil Quality in Organic Farms. *Journal of Agricultural Science.* 8(8): 42.

Spayd, S.E., Tarara, J.M., Mee, D.L., Ferguson, J.C. 2002. Separation of sunlight and temperature effects on the composition of Vitis vinifera cv. 'Merlot' berries. *American Journal of Enology and Viticulture*. 53: 171-182.

St. John, T.V., Coleman, D.C. 1982. The role of mycorrhizae in plant ecology. *Canadian Journal of Botany*. 61: 1005-1014.

Steenwerth, K., Belina, K.M. 2008. Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem. *Applied soil ecology*. 40(2): 359-369.

Stock, M., Gerstengarbe, F.W., Kartschall, T., Werner, P.C. 2004. Reliability of climate change impact assessments for viticulture. In *VII International Symposium on Grapevine Physiology and Biotechnology.* 689: 29-40

Strack, D., Fester, T. 2006. Isoprenoid metabolism and plastid reorganization in arbuscular mycorrhizal roots. New Phytologist. 172: 22–34.

Styczen, M.E., Morgan, R.P.C., 1995. Engineering properties of vegetation. *In* Slope Stabilization and Erosion Control: A Bioengineering Approach. Morgan, R.P.C., Rickson, R.J. (Eds.). pp. 5–58. E & F.N. Spon, London.

Taskin, E. et al., 2021. Combined Impact of No-Till and Cover Crops with or without Short-Term Water Stress as Revealed by Physicochemical and Microbiological Indicators. *Biology*. 10(1): 23.

Teasdale, J.R. 1993. Reduced-herbicide weed management systems for no-tillage corn (*Zea mays*) in a hairy vetch (*Vicia villosa*) cover crop. *Weed Technology.* 7: 879–883.

Tesic, D., Keller, M., Hutton, R.J. 2007. Influence of vineyard floor management practices on grapevine vegetative growth, yield, and fruit composition. American Journal of Enology and Viticulture. 58: 1-11.

This, P., Lacombe, T., Thomas, M.R. 2006. Historical origins and genetic diversity of wine grapes. *TRENDS in Genetics*. 22(9): 511-519.

Thomas, M.B., Wratten, S.D., Sotherton, N.W. 1991. Creation of'island'habitats in farmland to manipulate populations of beneficial arthropods: predator densities and emigration. *Journal of applied Ecology*. 906-917.

Tian, H., Drijber, R.A., Li, X.L., Miller, D.N., Wienhold, B.J., 2013. Arbuscular mycorrhizal fungi differ in their ability to regulate the expression of phosphate transporters in maize (Zea mays L.). *Mycorrhiza*. 23: 507-514.

Tiecher, T L., Ceretta, C.A., Ferreira, P.A., Lourenzi, C.R., Tiecher, T., Girotto, E., Nicoloso, F.T., Soriani, H.H., De Conti, L., Mimmo, T., Cesco, S., and Brunetto, G. 2016. The potential of Zea mays L. in remediating copper and zinc contaminated soils for grapevine production. *Geoderma*. 262: 52-61.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S. 2002. Agricultural sustainability and intensive production practices. *Nature*. 418: 671–7.

Tisdall, J.M., Oades, J.M., 1979. Stabilisation of soil aggregates by the root system of ryegrass. *European Journal of Soil Science*. 18: 429–441.

Tonitto, C., David, M.B., Drinkwater, L.E. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agriculture, Ecosystem and Environment. 112: 58–72.

Torres, N., Antolín, M.C., and Goicoechea, N. 2018. Arbuscular Mycorrhizal Symbiosis as a promising resource for improving berry quality in grapevines under changing environments. *Frontiers in Plant Science.* 9: 897.

Torres, N., Antolín, M.C., Garmendia, I., Goicoechea, N. 2018. Nutritional properties of Tempranillo grapevine leaves are affected by clonal diversity, mycorrhizal symbiosis and air temperature regime. *Plant Physiology and Biochemistry*. 130: 542-554.

Torres, N., Runze, Y., Sahap Kaan, K. 2021. Climate Change, Water Scarcity, Grapevine Physiology, Berry Metabolism, Arbuscular Mycorrhizal Fungi, Sustainable Viticulture. *Frontiers in Plant Science.* 11: 1664-462.

Torres, N., Yu, R., Kurtural, S.K. 2021. Inoculation with Mycorrhizal Fungi and Irrigation Management Shape the Bacterial and Fungal Communities and Networks in Vineyard Soils. *Microorganisms*. 9(6): 1273.

Tourte, L., Smith, R., Bettiga, L., Bensen, T., Smith, J., Salm, D. 2008. Post-emergence herbicides are cost effective for vineyard floor management on the Central Coast. *California Agriculture*. 62(1): 19-23.

Toussaint, J.-P., St-Arnaud, M., Charest, C. 2004. Nitrogen transfer and assimilation between the arbuscular mycorrhizal fungus Glomus intraradices Schenck & Smith and Ri T-DNA roots of Daucus carota L. in an in vitro compartmented system. *Canadian Journal of Microbiology.* 50: 251–260.

Trouvelot, S., Bonneau, L., Redecker, D., Van Tuinen, D., Adrian, M., Wipf, D. 2015. Arbuscular Mycorrhiza Symbiosis in Viticulture: A Review. *Agronomy for Sustainable Development*. 35(4): 1449-1467.

Uetake Y., Kojima T., Ezawa T. Saito M. 2002. Extensive tubular vacuole system in an arbuscular mycorrhizal fungus, *Gigaspora margarita*. *New Phytologist.* 154: 761–768.

Urban, J., Ingwers, M., McGuire, M.A., Teskey, R.O. 2017. Stomatal conductance increases with rising temperature. Plant Signaling & Behavior. 12(8): 3–6.

U.S. Global Change Research Program, 2014. *Centre for climate and Energy solutions website.* https://www.c2es.org/content/extreme-precipitation-and-climate-change/

Valdés-Gómez, H., Fermaud, M., Roudet, J., Calonnec, A., Gary, C. 2008. Grey mould incidence is reduced on grapevines with lower vegetative and reproductive growth. *Crop Protection.* 27: 1174-1186.

Valentine, A.J., Mortimer, P.E., Lintnaar, M., Borgo, R. 2006. Drought responses of arbuscular mycorrhizal grapevines. *Symbiosis*. 41: 127–133.

Van Der Heijden, M.G., Klironomos, J.N., Ursic, M., Moutoglis, P., Streitwolf-Engel, R., Boller, T., Wiemken, A., Sanders, I.R. 1998. Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. *Nature.* 396(6706): 69-72.

Van Der Heijden, M.G., Scheublin, T.R. 2007. Functional traits in mycorrhizal ecology: their use for predicting the impact of arbuscular mycorrhizal fungal communities on plant growth and ecosystem functioning. *New Phytologist*. 174(2): 244-250.

Van Der Heijden, M.G., Martin, F.M., Selosse, M.A., Sanders, I.R. 2015. Mycorrhizal ecology and evolution: the past, the present, and the future. *New phytologist.* 205(4): 1406-1423.

Van Geel, M., De Beenhouwer, M., Lievens, B., Honnay, O. 2016. Crop-specific and single-species mycorrhizal inoculation is the best approach to improve crop growth in controlled environments. *Agronomy for sustainable development*. 36(2): 1-10.

Van Geel, M., Verbruggen, E., De Beenhouwer, M., van Rennes, G., Lievens, B., Honnay, O. 2017. High soil phosphorus levels overrule the potential benefits of organic farming on arbuscular mycorrhizal diversity in northern vineyards. *Agriculture, Ecosystems & Environment*. 248: 144-152.

Van Leeuwen, C., Friant, P., Chone, X., Tregoat, O., Koundouras, S., Dubourdieu, D. 2004. Influence of climate, soil, and cultivar on terroir. *American Journal of Enology and Viticulture*. 55(3): 207-217.

Van Leeuwen, C., Darriet, P. 2016. The impact of climate change on viticulture and wine quality. *Journal of Wine Economics*. 11(1): 150-167.

Van Tuinen, D., Jacquot, E., Zhao, B., Gollotte, A., Gianinazzi-Pearson, V., 1998. Characterization of root colonization profiles by a microcosm community of arbuscular mycorrhizal fungi using 25S rDNA-targeted nested PCR. *Molecular Ecology*. 7: 879-887.

Vanden Heuvel, J., Centinari, M. 2021. Under-Vine Vegetation Mitigates the Impacts of Excessive Precipitation in Vineyards. *Frontiers in Plant Science*. 1542.

Varma, A., 2008. *In* Mycorrhiza. (3rd ed). Springer-Verlag Berlin Heidelberg.

Vaudour, E.; Leclercq, L.; Gilliot, J.M.; Chaignon, B. 2017. Retrospective 70 y-spatial analysis of repeated vine mortality patterns using ancient aerial time series, Pléiades images and multi-source spatial and field data. *International Journal of Applied Earth Observation.* 58: 234–248.

Venios, X., Korkas, E., Nisiotou, A., Banilas, G. 2020. Grapevine responses to heat stress and global warming. *Plants*. 9(12): 1754.

Verbruggen, E., Kiers, T.E. 2010. Evolutionary ecology of mycorrhizal functional diversity in agricultural systems. *Evolutionary Applications*. 3(5-6): 547-560.

Verbruggen, E., van der Heijden, M.G., Rillig, M.C., Kiers, E.T. 2013. Mycorrhizal fungal establishment in agricultural soils: factors determining inoculation success. *New Phytologist*. 197(4): 1104-1109.

Vestberg, M., Saari, K., Kukkonen, S., Hurme, T. 2005. Mycotrophy of crops in rotation and soil amendment with peat influence the abundance and effectiveness of indigenous arbuscular mycorrhizal fungi in field soil. *Mycorrhiza.* 15: 447–458.

Villanueva-Rey, P., Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. 2014. Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. *Journal of Cleaner Production*. 65: 330-341.

Victorino, G., Santos, E.S., Abreu, M.M., Viegas, W., Nogales, A. 2021. Detrimental effects of copper and EDTA co-application on grapevine root growth and nutrient balance. *Rhizosphere*. 100392.

Vrignon-Brenas, S., Celette, F., Piquet-Pissaloux, A., Jeuffroy, M.H., David, C. 2016. Early assessment of ecological services provided by forage legumes in relay intercropping. *European Journal of Agronomy.* 75: 89–98.

Vukicevich, E., Lowery, T., Bowen, P., Úrbez-Torres, J.R., Hart, M. 2016. Cover crops to increase soil microbial diversity and mitigate decline in perennial agriculture. A review. *Agronomy of Sustainable Development.* 36: 48.

Vyn, T.J., Faber, J.G., Janovicek, K.J., Beauchamp, E.G., 2000. Cover crop effects onnitrogen availability to corn following wheat. Agronomy Journal. 92, 915–924,

Wackers, F. L., van Rijn, P.C.J., Bruin, J. 2005. *In* Plant-provided food for carnivorous insects. A protective mutualism and its applications. Cambridge University Press, New York.

Walker, G.R., Zhang, L., Ellis, T.W., Hatton, T.J., Petheram, C. 2002. Estimating impacts of changed land use on recharge: review of modelling and other approaches appropriate for management of dryland salinity. *Hydrogeology Journal*. 10(1): 68-90.

Wang, B.; Qiu, Y.-L. 2006. Phylogenetic Distribution and Evolution of Mycorrhizas in Land Plants. *Mycorrhiza.* 16: 299–363.

Wang, T., Fan, Y., Xu, Z., Kumar, S., Kasu, B. 2021. Adopting cover crops and buffer strips to reduce nonpoint source pollution: Understanding farmers' perspectives in the US Northern Great Plains. *Journal of Soil and Water Conservation*. 76(6): 475-486.

Wang, W.-X., Zhang, F., Chen, Z.-L., Liu, J., Gou, C., He, J.-D., et al. 2017. Responses of phytohormones and gas exchange to mycorrhizal colonisation in trifoliate orange subjected to drought stress. *Archives of Agronomy and Soil Science*. 63: 14–23.

Welker, W.V., Glenn, D.M., 1988. Growth response of young peach trees and changes in soil characteristics with sod and conventional planting systems. Journal of the American Society for Horticultural Science. 113: 652–656.

Wheaton, A.D., McKenzie, B.M., Tisdall, J.M. 2008. Management to increase the depth of soft soil improves soil conditions and grapevine performance in an irrigated vineyard. *Soil and Tillage Research*. 98(1): 68-80.

Wheeler, S.J., Black, A.S., Pickering, G.J. 2005. Vineyard floor management improves wine quality in highly vigorous *Vitis vinifera* 'Cabernet Sauvignon' in New Zealand. New Zealand Journal of Crop and Horticultural Science. 33: 317-328.

Whipps, J.M. 2004. Prospects and limitations for mycorrhizas in biocontrol of root pathogens. *Canadian Journal of Botany*. 82:1198–1227.

Xi, Z.M., Tao, Y.S., Zhang, L., Li, H. 2011. Impact of cover crops in vineyard on the aroma compounds of Vitis vinifera L. cv Cabernet Sauvignon wine. *Food chemistry*. 127(2): 516-522.

Xu, Y., Castel, T., Richard, Y., Cuccia, C., Bois, B. 2012. Burgundy regional climate change and its potential impact on grapevines. *Climate dynamics*. 39(7): 1613-1626.

Yang, Y., Han, X., Liang, Y., Ghosh, A., Chen, J., Tang, M. 2015. The combined effects of arbuscular mycorrhizal fungi (AMF) and lead (Pb) stress on Pb accumulation, plant growth parameters, photosynthesis, and antioxidant enzymes in Robinia pseudoacacia L. *PloS one.* 10(12): e0145726.

Yang, Y., Liang, Y., Ghosh, A., Song, Y., Chen, H., Tang, M. 2015. Assessment of arbuscular mycorrhizal fungi status and heavy metal accumulation characteristics of tree species in a lead-zinc mine area: potential applications for phytoremediation. *Environmental Science and Pollution Research*. 22(17): 13179–13193.

Yao, R.J.; Yang, J.S.; Zhang, T.J.; Gao, P.; Yu, S.P.; Wang, X.P. 2013. Short-term e_ect of cultivation and crop rotation systems on soil quality indicators in a coastal newly reclaimed farming area. Journal of Soils and Sediments. 13: 1335–1350.

Yiridoe, E.K., Bonti-Ankomah, S., Martin, R.C. 2005. Comparison of consumer perceptions and preference toward organic versus conventionally produced foods: A review and update of the literature. *Renewable agriculture and food systems*. 20(4): 193-205.

Yücel, C., Özkan, H., Ortaş, I., and Yağbasanlar, T. 2009. Screening of wild emmer wheat accessions (Triticum turgidum subsp. dicoccoides) for mycorrhizal dependency. Turkish Journal of Agriculture and Forestry. 33(5): 513–523.

Zhang, L., Marguerit, E., Rossdeutsch, L., Ollat, N., Gambetta, G.A. 2016. The influence of grapevine rootstocks on scion growth and drought resistance. *Theoretical and Experimental Plant Physiology*. 28(2): 143-157.

Zohary, D., Spiegel-Roy, P. 1975. Beginnings of fruit growing in the Old World. Science. 1*87*(4174): 319-327.

Zolina, O. (2012). Changes in intense precipitation in Europe. In *Changes in flood risk in Europe*. 10: 97-119.

Zolina, O. 2012. Changes in intense precipitation in Europe. *In* Changes in Flood Risk in Europe, IAHS Special Publication (10th ed.) Z. W. Kundzewicz (International Association of Hydrological Sciences and CRC Press/Balkema). 97–120.

Zubek, S., Stefanowicz, A.M., Błaszkowski, J., Niklińska, M., Seidler-Łożykowska, K. 2012. Arbuscular mycorrhizal fungi and soil microbial communities under contrasting fertilization of three medicinal plants. *Applied Soil Ecology.* 59: 106-115.