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Review

Agricultural Practices for Biodiversity Enhancement: Evidence and Recommendations for the Viticultural Sector

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Abstract: Agricultural expansion and intensification worldwide has caused a reduction in ecological infrastructures for insects, herbaceous plants, and vertebrate insectivores, among other organisms. Agriculture is recognized as one of the key influences in biodiversity decline, and initiatives such as the European Green Deal highlight the need to reduce ecosystem degradation. Among fruit crops, grapes are considered one of the most intensive agricultural systems with the greatest economic relevance. This study presents a compilation of management practices to enhance biodiversity performance, which applies generally to the agricultural sector and, in particular, to viticulture, concerning the diversity of plants, semi-natural habitats, soil management, and the chemical control strategies and pesticides used in agricultural cultivation. Through a critical review, this study identifies a set of recommendations for biodiversity performance and their corresponding effects, contributing to the dissemination of management options to boost biodiversity performance. The results highlight opportunities for future investigations in determining the needed conditions to ensure both biodiversity enhancement and productive gains, and understanding the long-term effects of innovative biodiversity-friendly approaches.

Keywords: agrobiodiversity; recommendations; benefits; agriculture; viticulture

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1. Introduction

Throughout the past 50 years, anthropic activities have led to an unprecedented biodiversity crisis in human history at a planetary scale [1]. Although other significant periods of massive extinction have occurred in the past, the current loss of biodiversity is predicted to be characterized by the extinction of an even larger number of species at the fastest rate on record [2].

Two out of five plant species are estimated to be at risk of extinction [3]. In the most critical areas, the loss of species has reached over 75%, and worldwide, nearly 10% of all individuals have become extinct [2]. Reductions in habitat area have been pointed out as the leading cause of biodiversity loss worldwide [2]. Climate change is exerting a significant impact on biodiversity through the increased intensity and frequency of extreme weather events [4]. The destruction of natural ecosystems, due to agricultural intensification and overexploitation of natural resources, also a major threat to biodiversity [3].

With the growth of industrialized cities, the number of people engaged in the practice of agriculture progressively declined. Thereafter, farmers started to cultivate on a larger and more intense scale, leading to the industrial development of agriculture. Furthermore, especially after World War II, the tendency for cultivation of monoculture or few crop varieties, some soil practices, and the widespread use of synthetic pesticides and fertilisers has caused a continuous degradation in soil quality, along with a reduction in ecological infrastructures for several organisms (insects, herbaceous plants, and vertebrate insectivores, among others) [5,6]. Since 2000, the world's total forest area has decreased by 100 million hectares, although the rate of forest loss seems to have reduced in recent years [7]. Also, as a consequence of agricultural intensification, between 2015 and 2019, at least 100 million hectares of healthy and productive land were lost annually [7].

About 11% of the world's land surface is occupied with crops, and active grazing occupies an additional 30% [5]. With more than one-third of the world's land surface allocated to agriculture, and with the growing demand for agricultural goods, agriculture has been identified as one of the main factors influencing biodiversity decline [8].

Grapes cover the largest cultivated area among fruit crops, being considered both one of the most economically relevant fruit crops and one of the most intensive agricultural systems [9]. Given the environmental concerns regarding intensive agriculture, there has been growing interest in the concept of sustainability in the viticultural industry [10]. Adopting more environmentally friendly production practices can also open new business opportunities, as customers have become more sensitized about environmental issues, and some of them are willing to pay a higher price for sustainable products [10]. Moreover, the availability of water and energy is also a common concern in the sector. Such factors condition the production activities in this sector, due to their potential adverse environmental impacts [11].

Winegrowers are increasingly recognizing that viticulture might have a significant impact on biodiversity, which may negatively affect the corresponding ecosystem services [12,13]. Therefore, winegrowers are more aware of the importance of sustainability, and there is a growing tendency to accept its relevance. Additionally, initiatives such as the European Green Deal [14] highlight the need to reduce ecosystem degradation. Biodiversity enhancement is not exclusively related to environmental concerns. Diversity at multiple levels, such as the genetic, species, and habitat levels, enhances nutrient cycling, pest control, pollination, water regulation, soil health, soil carbon sequestration, and the consequent regulation of greenhouse gas emissions and water conservation [10,15,16]. Hence, promoting biodiversity in agricultural sectors can improve the stability and sustainability of agricultural systems by minimizing the hazards caused by conventional industrialized agriculture.

Farming practices have a significant impact on community abundance, exerting a representative influence on biodiversity [8]. The present study aims to review recommended practices for biodiversity enhancement in agricultural systems, and the corresponding effects of their implementation, with an emphasis on viticultural systems.

2. Materials and Methods

Similarly to other reviews that have been carried out [17,18], instead of following a strict keyword selection strategy to select the relevant literature, we followed an exploratory strategy, employing a critical review approach. Critical reviews rarely aim to perform a comprehensive search of all of the relevant literature [19]. Instead, this review approach intended to synthesize and critically analyze the literature on a broad topic, highlighting inconsistencies [19,20]. Since the aims of the research were to identify recommended practices promoting biodiversity in agriculture, provide an informative resource, and reveal areas requiring further research, a critical review was considered the most suitable method. Recommendations and results regarding the application of biodiversity-friendly practices were collected from Food and Agriculture Organization (FAO) guidelines, a reputable international organization oriented to tackle the world's main challenges related to agriculture [21], along with studies searched for in the Web of Science database.

The selection of recommended practices for biodiversity enhancement and corresponding effects (e.g., productivity, pest control, and soil health, among others) focused on six agricultural variables with recognized influence on biodiversity performance. These included the diversity of plants [22], semi-natural habitats [23], conservation agriculture practices, namely soil cover [24] and reduced tillage [25], and the use of synthetic fertilizers and pesticides [26]. Several biodiversity assessment methodologies considered the diversity of plants [25,27–29] and semi-natural habitats [25,30–32] as relevant indicators of biodiversity performance. Additionally, as described by the FAO [33], conservation agriculture practices, such as permanent soil organic cover and reduced tillage, enhance biodiversity and natural biological processes. The European Green Deal emphasizes the importance of reducing the application of synthetic fertilizers and chemical pesticides in addressing biodiversity loss, and thus, it aims to reduce the overall use and risk of chemical pesticides by 50%, and reduce the use of fertilizers by at least 20%, by 2030 [14]. In this study, some evidence on the agricultural sector is firstly presented, and then practices proposed and/or applied in viticulture are described.

3. Results

3.1. Diversity of Plants

The presence of different varieties or species of crops benefits the biodiversity performance of agricultural systems [25,34] and minimizes the proliferation of disease and insect pests that are stimulated by monoculture systems [22]. Furthermore, there is evidence that including leguminous plants in a cropping system can improve nitrogen fixation in the soil, positively influence overall yields, and maintain stability of income, as compared with monoculture systems [35,36].

The diversity of non-crop plant species, such as resident vegetation [37], cover crops, and hedgerows, also provides important ecological services. It has been recognized that the abundance of different resident/weed plant species, whether temporary or permanent, natural or sown, supports pollination and can improve soil fertility [38], as well as enhance microbial, nematode, and earthworm biomass and diversity [39]. Vegetal diversification has the advantage of restoring natural control of crop pests, replacing, at least partially, the use of pesticides [25]. Additionally, the prevalence of weed species in a field is associated with significant yield loss, due to competition for water and nutrients with crop plants [38]. It is expected that, given constant weed abundance, a weed community with increased diversity and evenness will be less competitive, and therefore more agronomically beneficial [38].

Regarding the importance of the diversity of plants in vineyard agroecosystems, Kehinde and Samways [40] concluded that it is possible to conciliate winegrape cultivation with the maintenance of autochthone biodiversity. Their results support the idea that vineyard ecosystems should conserve non-crop vegetation to ensure the presence of floral-rich species and, subsequently, the diversity of flower visitors [40].

Vegetation covers in vineyard inter-rows, as sources of pollen, nectar, and prey/hosts, can attract beneficial arthropods, functioning as foraging grounds, and supporting a richer community of pest natural enemies, especially where the availability of dense and sparse vegetated elements is assured [41]. Thiéry et al. [42] also supported the idea that using resident grass cover within vineyards might increase the biological control of tortricids. Monoculture vineyards can exhibit a lower abundance of predator and parasitoid species, as shown by Thiéry et al. [42], thus limiting pest biological control services, and augmenting pesticide use dependence. In their study on plant biodiversity in olive groves and vineyards, Cohen et al. [43] also highlighted that flora biodiversity is compatible with the economic sustainability of crop production. The authors recommended sowing low-competitive herbaceous species and conducting more extensive management of plot edges in order to improve the floral richness and enhance its role within ecological corridors on farms [43]. Promoting flower presence in vineyard inter-rows, using seed mixtures, and conserving resident vegetation can support wild pollinators [44]. Including a greater variety of nectar-producing plant species in seed plantations can enhance the ecosystem services offered by beneficial arthropods [45]. Floral resource and plant species richness positively influence the abundance of ladybirds, hoverflies, crab spiders, and caterpillar predation, providing a useful ecosystem service for the biological control of pests [45]. Recommendations for promoting plant diversity in agroecosystems, including vineyards, and their corresponding benefits are synthesized in Table 1.

Table 1. Recommendations and benefits of promoting the diversity of plants in vineyards and other agricultural systems.

	**Recommendations**	**Benefits (Compared to Monoculture)**	**References**
Vineyards	Biodiversity conservation, including floral-rich vegetation in inter-rows	• Improvement of biological control of pests by enhancing the diversity of flower-visitors, thus supporting the abundance and diversity of predators and parasitoids	[40–43,45]
Other Agricultural Systems	Cultivation of different crop varieties and/or crop species	• Minimization of the proliferation of disease and insect pests stimulated by monoculture systems	[22,25,34]
	Inclusion of leguminous plants into a cropping system	• Nitrogen fixation in the soil, potentially benefiting overall yields • Stability of income • Improvement of soil	[35,36]
	Conservation of diversity of non-crop vegetation	• Pollination support • Improvement of soil fertility and structure, and pest regulation • Enhances of microbial biomass, diversity, and activity • Avoidance of yield losses caused by dominant weed species	[38,39,46]

3.2. Semi-Natural Habitats

The proportion of semi-natural habitat in an occupied area is positively associated with species richness for vascular plants, birds, and arthropods [47]. Some methodologies have indicated a proportion of 5% of ecological infrastructures in utilized areas for agriculture [32]. However, in human-modified landscapes, including agricultural areas, a proportion of (semi-)natural habitat area equal to or higher than 20–25% is considered the minimum level needed to preserve a level of biodiversity compatible with the pollination of crops, pest and disease regulation, clear water maintenance, and soil erosion minimization [23].

In vineyard agroecosystems, different studies have shown the relevance of landscape composition in enhancing biodiversity and productive farm performance, due to its influence on pest control services through biological control [42,48,49]. Franin et al. [50] provided evidence that ecological infrastructures enhance the abundance and diversity of predatory arthropods in vineyards. Their study concluded that ecological infrastructures play an important role in the biological control of pests, especially when composed of wildflower strips in field paths and weedy areas. Papura et al. [51] reported that increasing the proportion of semi-natural habitats in a vineyard agroecosystem increases the predation rate of the grape berry moth by harvestmen. Muneret et al. [52] confirmed that semi-natural habitats significantly impact the biological control of pests in vineyard landscapes. It was demonstrated that reducing the area of semi-natural habitats can result in an increase in pest infestation levels, particularly mealybugs, mites, and phylloxera [52].

Besides promoting natural interactions for pest control, semi-natural habitats in vineyards foster the presence of different beneficial organisms that provide other relevant ecosystem services. Uzman et al. [53] recommended maintaining or establishing woody elements between vineyards, such as hedgerows, to promote the abundance and species richness of cavity-nesting bees and breeding birds. A study performed in vineyard landscapes in southwestern Germany concluded that planting hedges (for nesting), trees (as signposts), and woodland patches, and maintaining extensively used orchards and grassland areas (for feeding), can benefit the conservation of bird species [54].

While some studies have reported strong positive effects of semi-natural habitats on populations of insects, spiders, and birds, the impact on Orthoptera was found to be weak in vineyards of the region Palatinate in southwestern Germany [55]. Different taxa respond differently to the same vineyard management approaches, and therefore, they should be adapted to each specific context [41]. Nevertheless, there is evidence that the presence of semi-natural habitats in vineyard systems favors both biodiversity and biological pest control. Recommendations for conserving semi-natural habitats, and their corresponding benefits, are summarized in Table 2.

Table 2. Recommendations and benefits of conserving semi-natural habitats in vineyards and other agricultural systems.

	Recommendations	**Benefits**	**References**
Vineyards	Maintenance of semi-natural habitat, including wildflower strips of field paths and weedy areas	• Biological control of pests (tortricid moths and grape berry moths, mealybugs, mites/and phylloxera) • Enhance the abundance and diversity of predatory arthropods in vineyards	[42,50–52]
	Maintenance of semi-natural habitat, including woody elements	Abundance and species richness of cavity-nesting bees and breeding birds that provide relevant ecosystem services	[53–55]
Other Agricultural Systems	Conservation of a proportion of semi-natural habitat area equal or higher than 20%–25% per km^2	Preservation of biodiversity's capacity to: • Pollinate crops • Regulate pests and diseases • Maintain clear water • Limit soil erosion	[23]

3.3. Soil Management

The FAO recommends maintaining a permanent soil organic cover of at least 30% with crop residues and/or cover crops [33]. A permanent organic cover offers soil protection from the impact of extreme weather conditions and compaction and helps to preserve soil moisture [33]. Cover crops, in particular, can boost the biodiversity of many taxa, namely invertebrate pest predators and pollinators [56]. The use of plant residues or other organic suitable material as a protective cover for the soil surface, known as mulching [22], can increase soil organic matter and the availability of nutrients. Depending on plant composition and edaphoclimatic conditions, it can also conserve soil moisture due to the diminution of evaporation, stabilize temperature in the first few centimeters of soil, contribute to soil erosion reduction, and improve soil fertility and weed suppression [22,35,57].

Contrastingly to the application of crop residues, living plant coverage may result in competition for light, water, space, and nutrients for the main crop and compromise economic feasibility. Thus, living plant coverage requires careful management [22].

3.3.1. Cover Crops in Vineyards

Cover crops can be sown or spontaneous (resident plant species), depending on their origin. When sown, *Fabaceae* (legume), *Poaceae* (grasses), and *Brassicaceae* species are usually selected, either in seed mixtures or monoculture [58].

The results of a study in Mediterranean vineyards suggested that arachnid biodiversity is favored by the conservation of a high proportion of ground vegetation cover [59]. One should reduce inflorescence cutting and damage to increase flower cover and boost plant species richness, thus encouraging the presence of beneficial arthropods and improving the biological control of pest insects [45]. Bernaschina et al. [60] suggested that permanent cover crop promotes biodiversity and soil and plant health in vineyards. Grapevine with permanent cover crop management exhibited a low incidence of latent *Botrytis* infections in berries as compared to those that underwent herbicide weeding [60].

Although negligible in the short-term, additional benefits of using inter-row cover crops during two consecutive growing seasons were reported, namely on grapevine physiology and mineral nutrition, with no unfavorable effects on water footprint [61].

A study on the effect of inter-row management intensity demonstrated that, due to the implementation of complete or alternating vegetation cover with bare soil, the clay content of the soil increased the abundance of both the analyzed taxa, i.e., Acari and Collembola, in nine Austrian vineyards with a humid continental climate and warm summers [62]. Therefore, both management modalities were considered feasible to support soil mesofauna in vineyard ecosystems [62].

The implementation of different soil management approaches, when combined, can have a more significant impact than isolated practices. For instance, combining cover crops with no-tillage resulted in a higher mean soil carbon sequestration rate compared with the cover crops or no-tillage alone [63]. Combining a legume and a non-legume in cover cropping resulted in a higher mean soil carbon sequestration rate (t C/ha/yr.) in arable land, compared to using either cover crop alone [63].

The presence of vegetation cover in vineyards can also have a positive impact on soil health by improving soil carbon levels and, consequently, reducing rates of soil nitrogen leaching. The associated improvements in soil multi-functionality and soil bacterial activity have been found to be especially relevant in the long-term [64].

Despite the benefits of grass cover for vineyard pest control [49] and biodiversity [62], this practice can foment competition with vine plants for nutrients and water, an issue especially relevant in Mediterranean regions where water scarcity is a major challenge for agricultural systems [65,66]. Therefore, vineyard cover crops must be carefully managed to avoid competition for water and nutrients between weeds and the maincrop, as this might otherwise compromise the profitability of the vineyard. However, there is evidence that it is possible to maintain intercropping groundcovers in vineyards without negative effects on yields, even in Mediterranean climates [67]. To achieve sustainable benefits, one must select cover crop species that are less competitive to reduce the negative impact on grape yield and improve soil properties [68,69].

3.3.2. Organic Death Mulches in Vineyards

Using organic death material to cover the soil surface in vine rows serves as an interesting alternative to cover crops, minimizing the presence of plants that impair optimal vine growth [68]. In general, mulching potentially enhances the density and diversity of carabids, hymenopteran parasitoids, dipteran parasitoids, hemipterans, and spiders, with no harmful effects on insect pest density in vineyards [42].

A study on a commercial vineyard in northeast Spain concluded that the application of organic death mulches undervine, especially those containing straw and grapevine pruning debris, was an effective technique to control excessive weed cover [68]. The use of spent mushroom compost as mulch treatment, despite being associated with significant coverage of weeds, boosted the composition of the soil, making it more porous and improving surface water retention. These results were verified in north-eastern Spain with a soil classified as haplocalcid semi-arid soil according to the Soil Resource base. Compared with conventional methods, namely the application of herbicides and undervine tillage, the use of organic materials to cover the soil promoted a reduction in more than 20% of known noxious grapevine weed species that harm the optimal growth of vine crops. Additional benefits of organic mulch use include the improvement of the physical and chemical properties of the soil, the reduction of chemical inputs, improvement of the surface water holding capacity, and attenuation of extreme temperature peaks [68]. It was also demonstrated that the use of organic mulches composed of almond shell and chopped pine wood mulch, combined with mechanical cultivation with an in-row tiller and using an in-row mower to control spontaneous cover, resulted in lower weed cover in mulched treatments and better vine water status across three consecutive growing seasons [70]. Additionally, soil mulching helped prevent water loss via evaporation, proportioning an increasing availability of soil water, contributed to better weed control, and increased income due to the avoidance of costs associated with mechanical weeding. Greater vegetative development was achieved overall [70]. Recommendations for promoting soil cover are displayed in Table 3.

Table 3. Recommendations and benefits of soil cover in vineyards and other agricultural systems.

Soil Cover	**Recommendations**	**Benefits**	**References**
Vineyards	Maintenance of a high proportion of ground vegetation cover, nectariferous plants	• Improvement of biological control of pest insects • Improvement of soil health • Enhancement of biodiversity and plant health in vineyards	[45,60,64]
	Complete or alternating vegetation cover	• Enhancement of soil mesofauna	[62]
	Organic mulching in the vine row	• Minimization of the presence of plants that impair optimal vine growth • Reduction of water loss through evaporation, proportioning an increase in the available soil water • Increased income due to the avoidance of costs of mechanical weeding, and greater vegetative development achieved	[68,70]
Other Agricultural Systems	Maintenance of a permanent soil organic cover of at least 30% with cover crops	• Enhancement of diversity of many taxa, namely invertebrates, invertebrate, pest predators, and pollinators • Soil protection from the impact of extreme weather patterns • Preservation of soil moisture • Minimization of soil compaction	[33,56]
	Maintenance of permanent soil organic cover of at least 30% with crop residues (mulching)	• Soil organic matter increasing (depending on the type of mulch and edaphoclimatic conditions) • Soil moisture conservation • Soil temperature stabilization • Soil erosion reduction • Weed suppression	[22,33,35,57]

3.4. Reduced Tillage

Reduced tillage is known as one of the main principles of conservation agriculture. It describes the principles of disturbing the soil as little as possible and retaining at least 30% of the previous crop's residues on the soil surface [22]. Reduced tillage contributes to the mitigation of soil ecological pressure, reductions in production costs, and preservation of soil quality and biological activity [71]. In semi-arid conditions, reduced tillage has been found to facilitate significant improvements in soil quality, soil diversity, microbial populations, soil organic carbon concentration, and beneficial nematodes [72]. Conservation tillage is a sustainable agricultural practice that involves minimum soil disturbance during planting, leaving the soil undisturbed with crop residues after harvest, and reducing soil erosion and runoff. On the contrary, conventional tillage practices have negative impacts on the soil and environment, potentially leading to the diminution of organic matter content, and fostering soil compaction, erosion of the superficial soil layer, and the extinction of soil-dwelling fauna [22].

In vineyards, as well as in other agricultural systems, detrimental effects on beneficial arthropods due to conventional tillage have been reported [42]. Kratschmer et al. [44] showed that the abundance of eusocial wild bees was higher in untilled inter-rows, while solitary wild bees were more abundant in alternating-tilled vineyards. Therefore, the study suggested that varying tillage frequency (no tillage vs. alternating tillage) may be a suitable management strategy to provide diverse habitats that benefit both eusocial and solitary bees [44]. Concerning the impacts of tillage on flora, the results obtained by Kesser et al. [64] recommended reducing the use of herbicides and tillage to promote a less competitive plant community mainly composed of perennial species in the *Poaceae* (Grass) and *Fabaceae* families in viticultural landscapes [64]. Kesser et al. [64] verified a highly positive correlation between lower management intensity (less tillage and herbicide application) and higher levels of plant coverage, plant biomass, plant species richness, soil total nitrogen, and soil water infiltration. Thus, in irrigated vineyards, it is recommended to maintain a low level of management intensity, which allows complete vineyard floor coverage, positively contributing to the productivity and resilience of the crop [64]. Regarding soil health in viticulture environments, the combination of organic amendments with no-tillage led to a considerable increase in soil organic carbon amounts [73]. Moreover, Sánchez-Moreno et al. [72] highlighted the relevance of complementing a reduction in the use of conventional pesticides and mineral fertilizers with conservation practices, including reduced tillage or cover cropping, to protect soil health in semi-arid Mediterranean agroecosystems. Agricultural practices that involve no-tillage, along with the use of non-chemical fertilizers and non-chemical pest management, can keep organic carbon amounts below the ground [63]. This approach has the potential to support climate goals, biodiversity, long-term soil productivity, as well as human health and wellbeing [63]. A medium-term field experiment performed by López-Piñeiro et al. [74] demonstrated that no-tillage practice combined with native vegetation cover had the effect of improving the soil's organic carbon and water content, along with boosting its aggregate stability and the diversity of soil microorganisms while also reducing the soil's penetration resistance. This way, the obtained results suggested that no-tillage with native vegetation conservation may be an interesting strategy to restore commonly found degraded soils in vineyards for semi-arid regions [74]. Recommendations related to tillage are summarized in Table 4.

Table 4. Recommendations and benefits concerning tillage in vineyards and other agricultural systems.

Tillage	Recommendations	Benefits	References
Vineyards	Maintenance of a low level of management intensity or variations in tillage frequency (no tillage vs. alternating tillage)	• Diverse habitat provisioning, which benefits both eusocial and solitary bees • Productivity and resilience of vineyards	[44,64]
	No-tillage with native vegetation management	• Soil quality by increasing the soil's organic carbon, aggregate stability, water content, and diversity of microorganisms • Soil penetration resistance reduction	[74]
Other Agricultural Systems	Minimization of soil disturbance and retaining at least 30% of the preceding crop's stubble on the soil surface	• Mitigation of soil ecological pressure • Reduction of production costs • Preservation of soil quality (preventing loss of organic matter, compaction, and erosion) • Biological activity	[22,71]

3.5. Fertilisers

Inorganic fertilizer use causes long-term changes in energy and nutrient cycling and storage that disturb regular ecosystem functioning due to changes in microbial activity [75,76]. It has been found that the frequent use of these fertilizers in agriculture may negatively affect mammals, birds, amphibians, earthworms, arthropods, microarthropods, and microorganisms [75]. To minimize fertilizer-associated damage to biodiversity and achieve more sustainable agricultural production, the use of organic soil amendments, namely manure, compost, biochar, and plant residues, is recommended to replace, at least partially, the application of inorganic fertilizers [17,25,36]. By doing so, it is possible to improve the soils' physicochemical and biological properties, providing and retaining nutrients and mitigating climate change [17]. Additionally, the reduction of inorganic fertilizer application leads to the minimization of soil contamination with elements that are potentially harmful to consumer health, while also minimizing air and groundwater pollution [31,77].

A study by Villat and Nicholas [63] aimed to quantify the annual soil carbon sequestration of regenerative practices in vineyards, namely agroforestry, cover cropping, legume cover cropping, animal integration, non-chemical fertilizers, non-chemical pest management, and no-tillage. The results showed that all the regenerative practices, including non-chemical fertilizers, as well as non-chemical pest management, improved below-ground carbon sequestration. Thus, in this study, the use of non-chemical fertilizers is referred to as a practice that supports climate goals and biodiversity, long-term soil productivity, and human health [63]. Comparing the effects of organic and synthetic fertilizer application in a Mediterranean vineyard, Lazcano et al. [78] concluded that organic fertilizers (1120 kg ha^{-1} of a mixture composed of dehydrated poultry manure, feather meal, rock phosphate, and potassium sulphate) reduced the relative abundance of plant-parasitic or herbivore nematodes. Additionally, organic fertilizer application increased the rate of nitrogen mineralization, strengthening soil function and soil health. Nonetheless, in the 1-year study, organic fertilization was associated with a decrease in vine yields [78]. Distinctly, Marín-Martínez et al. [79] reported that organic amendment application enhanced grape yield and the fertility of the soil, especially in the case of drip-irrigated vineyards. It is noteworthy that this effect was verified in the short-term, as despite increases in soil health being associated with higher crop yields, this effect is not always verified. Thus, there is a need to adjust the timing and rates of application of organic fertilization to obtain benefits for both biodiversity and yield. Nevertheless, an investigation performed over 10 years in a vineyard under semi-arid conditions concluded that organic fertilization applications maintained similar levels of crop yield to those obtained under the inorganic fertilization system. The addition of grapevine pruning with a legume cover crop and grapevine pruning with sheep manure as organic amendment types had a significant medium-term effect on soil fertility [80]. When compared with inorganic fertilizer application, the soil microbial community biomass, function, and composition were more favorable. Moreover, the contents of total organic carbon, total nitrogen, available phosphorus, water-soluble carbohydrates, and stable aggregates were augmented [80]. Recommendations on fertilizer use are summarized in Table 5.

Table 5. Recommendations and benefits concerning fertilizer use in vineyards and other agricultural systems.

Fertilisers	Recommendations	Benefits	References
Vineyards	Non-chemical fertilizer use	• Climate goals and biodiversity support • Long-term soil productivity • Human health and wellbeing	[63]
	Organic amendments	• Reduction of the relative abundance of plant-parasitic or herbivore nematodes • Soil function and soil health strengthening • Enhancement of the soil microbial community biomass, function, and composition	[78–80]
Other Agricultural Systems	Use of organic soil amendments, namely manure, compost, biochar, plant residues, among others	• Improvement of physical, chemical, and biological properties of soils, • Provision and retaining of nutrients • Climate change mitigation	[25,36]
	Avoidance of the application of inorganic fertilizers	• Minimization of soil contamination with potentially harmful elements to consumer health • Minimization of air and groundwater pollution	[31,77]

3.6. Pesticides

The need to reduce chemicals used in agriculture has been pointed out in different parts of the world due to the hazards their use cause both to human health and the environment [81]. The wide availability and application of pesticides has resulted in soil, air, and water pollution, and has harmed non-target organisms [82].

Pesticide use is known as one of the main agricultural practices causing pollinator decline in agricultural landscapes [40]. A study on the impact of pesticides on the local biodiversity of stream invertebrates in Europe and Australia concluded that pesticides substantially affected both the species and family richness, with losses of up to 42% in the recorded taxa [1]. Furthermore, non-target pesticide poisoning has been reported as causing the death of bees, fish, birds, and small mammals, in addition to affecting bird reproduction and human health [82,83]. Even if pesticides are applied at recommended rates, in the long-term their recurrent application jeopardizes biochemical balance, affects local metabolic and enzymatic activities, and consequently reduces soil fertility and the productivity of agricultural systems [84].

3.6.1. Replacement of Insecticides and Fungicides

One way to replace the use of pesticides is through top-down suppression of pests by their natural predators, i.e., biological control [85,86]. For example, encouraging the presence of bats in agricultural ecosystems by providing shelter boxes is a possible conservation biological control tactic for pest management, as bats are known as relevant pest suppressors [86–88]. Incrementing and conserving ecological infrastructures within farms, such as cover crops, biodiverse hedgerows, and flowering strips, can also contribute to reducing pesticide use by enhancing pest biological control, as mentioned previously. In addition to employing natural pest predators for pest control, farmers can also use repellent plants and botanical sprays instead of synthetic pesticides [36]. Botanical sprays can be derived, for instance, from the seeds of trees, plant essential oils, pyrethrum extracted from flowers, and the crude aqueous extracts of plants [57]. The use of companion plants, including trap plants, plants altering host plant selection by insect pests, and plants attracting the natural predators of pests, poses another alternative pest management strategy [81,89–91]. Another pest management tactic is the use of pheromones, which are species-specific volatile compounds, to disturb the sexual reproduction of targeted insect pests, i.e., mating disruption [57,92]. Pheromones or other semi-chemicals can also be used isolated or in conjunction to attract pests and reduce damage to crops by employing mass-trapping or lure-and-kill tactics [81]. Furthermore, biofumigation can be used in combination with other integrated pest management tactics [81] through the use of plants mainly belonging to the *Brassica* family that produce biocidal molecules. This is a bio-disinfection approach that suppresses soilborne pathogens by producing volatile compounds through the liberation of glucosinolates [93]. By preferentially using non-chemical methods to control pests, decision-makers in the agricultural sector can promote the minimization of damage to crops, increase productive gains, minimize soil, water, and atmosphere pollution, reduce contamination of the food chain, and mitigate the occurrence of consequent diseases in humans and death in other non-target organisms (bees, fish and birds) [82,84].

Evidence in Vineyard Systems on Insecticide Use Alternatives

Thiéry et al. [42] highlighted that the mean abundance of natural predators in vineyards is related to the distance from woody vegetation. Their study found that grapevine plants closer to woody habitats (distances up to 40 m) exhibited higher parasitism and predation levels of tortricid moths [42]. The presence of ecological infrastructures, such as alley cropping, windbreaks, hedgerows, and multi-story cropping, within and around vineyards, can increase the abundance of predaceous insects and bats and, subsequently, increase parasitism and predation rates, decrease the use of pesticides, and promote economic advantages [94]. Besides conserving native forest remnants and shrubs, agricultural managers can also promote artificial wetlands and increase artificial roosting opportunities through, for instance, the installation of bat boxes in vineyards to encourage biological pest control [9,59]. Etienne et al. [95] studied the effect of semi-natural habitats (grassy and wooded habitats) on pesticide use. The investigation revealed that conventional fields are more likely to be sprayed for insect pests and pathogens when located in landscapes with higher proportions of semi-natural habitats. However, the same effect was not verified in organic fields. This underscores that the benefits of a higher proportion of semi-natural habitats for agricultural production are not linear. They depend on spatial extents and the type of farming practices at the field scale, among other factors [95]. Mating disruption is an environmentally-friendly pest management tactic which has been effectively applied to control grapevine pests, such as the European vine moth and the vine mealybug, in different producing regions, contributing to reducing the dependence on insecticides [92,96].

Evidence in Vineyard Systems on Fungicide Use Alternatives

To prevent pathogen attacks on grapevines, products based on living microorganisms (biofungicides), bacterial derivatives, or botanicals, can be used as alternatives to synthetic fungicide applications [97]. Moreover, some studies have mentioned the planting of fungus-resistant varieties as a recommended approach to more sustainable viticulture [98–100]. The cultivation of these varieties led to the significant enhancement in the abundance of beneficial arthropods and predatory mite (*Phytoseiidae* and *Tydeidae*) density in both organic and conventional production types and contributed to the reduction of fungicide application [98,99]. Pennington et al. [100] reported enhanced densities of *Lobesia botrana* predators and reduced damage to inoculated grape bunches due to a reduction in fungicide applications in grapevine cultivars resistant to powdery and downy mildew. Improved pest control is a potential additional benefit of planting fungus-resistant varieties that might benefit other kinds of agricultural systems. Recommendations and benefits concerning reductions in insecticide and fungicide use are shown in Table 6.

Table 6. Recommendations and benefits concerning the reduction of insecticide and fungicide use in vineyards and other agricultural systems.

Insecticides and Fungicides	**Recommendations**	**Benefits [1]**	**References**
Viticulture	Incorporation of trees into and around vineyards Increasing artificial roosting opportunities, with for instance the installation of bat-boxes Plantation of fungus-resistant varieties (1)	• Reduction of fungicide application, avoiding the hazards caused by their use • Augment of the abundance of arthropods in general and beneficial arthropods in particular (1)	[94] [9] [98–100]
Other Agricultural Systems	Encourage the presence of natural enemies of pests, for instance, by providing shelter boxes for bats (1) Use of repellent plants and botanical sprays instead of synthetic pesticides Sticky Traps Biofumigation Pheromones or other volatile compounds, like attractants and infochemicals Increasing landscape heterogeneity (2) Incorporation of companion crops, and also catch and trap crops	• Enhancement of pollination (1) • Improvement of arthropod diversity and bat activity (2) • Crop losses reduction, through biological pest suppression • Minimization of damage to crops and productive gains • Minimization of soil, water, and atmosphere pollution, contamination of the food chain, and consequent diseases caused in humans and deaths of other non-target organisms (bees, fish, birds, etc.) caused by insecticide and fungicide application	[85–87] [82,84] [81] [81] [57,81] [88] [81]

[1] The benefits mentioned are transversal to all recommendations and benefits (1) and (2) are specific to recommendations (1) and (2), respectively.

3.6.2. Replacement of Inorganic Herbicides

Herbicide application can be avoided through the application of more sustainable alternative options for the management of weeds, namely:

- Use of hydrolats (e.g., *Thymus vulgaris* L.) and other biopesticides [36,101,102].
- Preventive measures, namely the use of clean seeds, keeping the seedbed, bunds, and irrigation channel tools and farm machinery free from weeds, use of well-decomposed organic manures, and controlling weeds before they achieve the reproductive stage [35].
- Soil solarization. This technique involves precluding seed germination by raising soil temperatures to 50–55 °C at a depth of 5 cm and attaining a temperature higher than 40 °C in surface layers [35]. However, this technique implies changes in microbial functional biodiversity through altering biogeochemical and edaphic processes. The combustion of organic matter and volatilization of some nutrients also occurs.
- The diversification of crops and farming practices, such as tillage, sowing date, and fertilization, can increase biotic environmental heterogeneity and prevent the dominance of most competitive weeds [38].
- The use of mulches contributes to light exclusion, the creation of physical barriers to seed emergence, and allelopathy, acting as an effective mechanism for weed control [35].
- The use of mechanical tools, for instance, torsion weeders, finger weeders, brush weeders, weed blowers, and flex-time harrows [35,103].

These methods can minimize the mortality caused by non-target organisms (worms, fish, etc.), the decline of pollinators, the deterioration of water quality, and other hazards caused by herbicide application [104]. Soil solarization also provides the benefit of improving soil texture and nutrient availability [35].

In vineyards, the application of biostimulants can serve as an interesting replacement for the use of conventional agrochemicals, including fungicides, insecticides, and herbicides, with the goal of maintaining crop health and quality [105].

Through the analysis of communities in Mediterranean vineyards after five years of mowing, Bopp et al. [106] concluded that this practice facilitated a higher content of nitrogen compared with communities characterized by five years of chemical weeding and five years of tillage. Mowing can be an adequate strategy to reduce herbicide use since it is associated with higher biomass, nitrogen content, and decomposability potential of weeds [106]. According to Griesser et al. [107], regularly mowing under-vine vegetation could be a viable alternative to using herbicides. The study showed that having a permanent vegetation cover below the vines significantly enhances soil microbial activity compared to herbicide application. This positive tendency increased over three years of performance [107]. However, having a permanent vegetation cover can increase crop competition for water. Therefore, sowing non-competitive herbaceous species can be an appropriate ecological strategy for maintaining crop productivity [43].

Additionally, Kesser et al. [64] verified that reducing both tillage and the use of herbicides has the potential to foster a plant community primarily composed of less competitive species, facilitating the process of weed control.

Herbicide use can also be avoided through permanent cover crops undervine, without negative effects on vine vigor or grape must quality [60].

If the use of herbicides is considered indispensable, farmers can at least replace their use across the entire field with alternating applications. For example, in German viticulture, herbicides are generally only applied in the area right beneath the vines, and the vegetation cover under at least every second inter-row is retained, which promotes the presence of flower-visiting insects [53].

Recommendations and benefits concerning herbicide use for agriculture (fields and vineyards) are summarized in Table 7.

Table 7. Recommendations and benefits concerning herbicide use in vineyards and other agricultural systems.

Herbicides	**Recommendations**	**Benefits**	**References**
Viticulture	Application of biostimulants	• Reduction of herbicide application, avoiding the hazards caused by their use • Favoring higher nitrogen content, and decomposability potential of weeds (1)	[105]
	Sowing of non-cosmopolitan and non-competitive herbaceous species and preference for mechanical practices		[43]
	Mowing (1)		[106]
	Mechanical weed control or permanent or temporary soil cover		[103]
	Permanent cover crop undervine		[60]
Other Agricultural Systems	Use of hydrolats and other biopesticides for ecological weed management	• Reduction of herbicide use, minimizing the mortality caused to non-target organisms (worms, fish, etc.), the decline of pollinators, deterioration of water quality, and other hazards caused by herbicide application • Improvement of soil nutrient availability (1)	[36,101,102]
	Implementation of preventive measures, namely: • Using clean seeds • Keeping the seed bed free from weeds • Using well-decomposed organic manures • Keeping the bunds and irrigation channels free from weeds • Keeping tools and farm machinery clean • Controlling weeds before they attain the reproductive stage		[35]
	Solarization (1)		[35]
	Use of mulches		[35]
	Use of mechanical tools such as torsion weeders, finger weeders, etc.		[35]

4. Discussion

Sustainability has become a global concern in many economic sectors. Given the impact of the industrialization of agriculture on habitat degradation and the natural balance of ecosystems, boosting biodiversity in this sector is of growing interest. Existing reviews on agricultural practices to promote biodiversity have focused on assessing drivers and constraints of on-farm diversity [108] and assessing the effectiveness of common functional agrobiodiversity measures employed in Europe [56]. This review focused on the summarization of recommended practices and respective effects for the generality of the agricultural sector and for viticulture, in particular.

Several beneficial effects can be obtained through the implementation of recommendations to enhance biodiversity, such as natural control of pests, minimization of damage to crops, cost reductions (e.g., due to the avoidance of chemical control mechanisms), soil health improvement, minimization of erosion, preservation of soil moisture, pollination enhancement, and mitigation of climate change, among others.

Nonetheless, this review also allowed us to identify knowledge areas that need further research to promote the implementation of more ecological practices concerning biodiversity conservation. Three main topics can be highlighted:

1. *Yield reduction* vs. *biodiversity enhancement.* While some studies have reported increased yield [79] or yield maintenance [67,68] after implementing functional agrobiodiversity practices in vineyards, others have reported yield reductions mainly associated with the use of cover crops [69], due to competition with the main crops for water and nutrients [78]. Further investigation is needed to determine which conditions should

be assured to benefit both biodiversity and crop yields when applying cover crops (e.g., selection of cover crop species and management) and organic amendments (e.g., composition, timing, and rates of application).

2. *Long-term effect of biodiversity-friendly approaches.* Further and more extended investigations are required to understand the long-term effects of different agricultural practices for climate change mitigation, particularly in semi-arid regions, which are especially vulnerable to the impacts of climate change. Establishing a more in-depth understanding of the active contributions of biodiversity-friendly approaches in the long-term, such as the use of organic amendments [79] and biostimulant applications [105], to not only the environment's well-being but also the stability and productivity of agricultural systems, could promote a generalized and effective transition to sustainability.
3. *Develop information technologies to promote responsible agricultural management.* The effects of agricultural practices in enhancing biodiversity are hard to generalize due to the multiple conditioning factors. For this reason, site-specific solutions are required to conciliate the support of ecosystem services with productivity. The development of robust information systems can empower decision-makers at farm and/or regional levels to adequate their management strategies to effective biodiversity enhancement. Productivity is also a major concern in the agricultural sector, not only for economic reasons, but also to satisfy the food demand, which is expected to increase due to the overpopulation phenomenon. For this reason, information technologies to support agricultural management should inclusively address the productivity concerns in order to promote farm economic sustainability. The form of literature review followed is associated with the risk of neglecting some relevant publications in the field, since a non-comprehensive approach was employed. However, the present compilation of good practices makes a useful contribution not only to demonstrate areas for further research, but also to disseminate alternatives to conventional practices to protect both biodiversity and the stability of agricultural systems. Such dissemination can potentially help agricultural managers achieve the goals proposed by the European Green Deal strategy and comply with national/international legislation, which is expected to be increasingly demanding.

5. Conclusions

The destruction of natural ecosystems due to agricultural intensification and overexploitation of natural resources has been a key driver of the unprecedented biodiversity loss observed over the last 50 years.

Through the compilation of recommended practices for the agricultural sector and one of the most economically relevant and intensive subsectors—viticulture—this review contributes to the dissemination of management options to halt biodiversity loss. It was shown there is a need for more investigation on:

- Determining the needed conditions to assure both biodiversity enhancement and productive gains concerning the use of cover crops and organic amendments.
- The long-term effect of biodiversity-friendly approaches on mitigating climate change, and on the productivity and stability of agricultural systems.
- The development of information technologies to empower decision-makers on farm and/or regional levels to adequate their management strategies in order to effectively enhance biodiversity and productivity.

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