A META-ANALYSIS OF THE ECOLOGICAL IMPACT OF VITICULTURAL PRACTICES ON SOIL BIODIVERSITY

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Abstract:

Context and purpose of the study - Viticulture is facing two major challenges – climate change and agroecological transition. The soil plays a pivotal role in these transition processes. Therefore, soil quality and adequate soil management are key levers for an ecologically and economically sustainable viticulture. Over the last 15 years, numerous studies evidenced strong effects of viticultural practices on the soil physical, chemical and biological quality. However, to date a global analysis providing a comprehensive overview of the ecological impacts of viticultural practices on soil biological quality is missing.

Material and methods - We conducted a meta-analysis of the international literature in order to rank viticultural production systems and practices according to their impact on soil biodiversity and functioning in the context of the agro-ecological transition. We screened about one hundred articles and gathered data on more than 50 viticultural factors and 230 soil biological parameters. The viticultural factors were classifed into different groups, i.e., the land-use, the method of production, practices. The biological groups were distributed into macrofauna, mesofauna, microfauna, and soil microorganisms. The measured parameters addressed 3 main properties of soil biological quality: biological heritage, functional and sanitary states of the soils.

Results - The results show that the soil microorganisms are threefold to fourfold higher under organic viticulture than under conventional viticulture in terms of biomass, respiration, and activity; and that biodynamic viticulture shows a similar trend than organic viticulture. Tillage, the absence of soil cover and mineral fertilization are significantly deleterious to the whole soil biodiversity, whereas cover crops, organic fertilizers and addition of grapevine pruning wood are beneficial. Pesticides—especially herbicides—have an ecotoxicological impact on soil organisms, notably on nematodes with losses of up to two-thirds of individuals. Our study also highlighted some unexplored themes which need to be investigate such as pesticides other than herbicides, copper use as fungicide, or biocontrol tools. A well knowledge of the impact of viticultural practices on the soil biodiversity should provide the key for improving the sustainability of viticultural soils to preserve them from irreversible degradations with substantial consequences on the soil ecological and agronomical services for vine production. This work and all the informations and results have been published in 2020 in Environemental Chemistry Letters (see Karimi et al. 2020).

Keywords: Biodiversity, Soil, Viticulture, Ecological quality, System of production, Viticultural practices.

1. Introduction

The wine-growing sector, along with the agricultural sector, must undergo a major evolutionary process—namely, agro-ecological transition (Wezel et al. 2009). This transition aims to turn the intensive post-war agricultural model into a sustainable and durable model based on agronomical and ecological levers. The soil represents a pivotal role in this transition process because it supports production, regulates water, air, and nutrient supplies, and is the major biodiversity reservoir of our planet (FAO 2015). Therefore, soil quality and adequate soil management are key levers of an ecologically and economically sustainable viticulture.

Soil quality is determined by its chemical, physical, pedological, agronomical, and ecological components. In the context of wine production, the first four components have long been measured, analyzed, and interpreted as "terroir" effects or agronomical levers. The biological quality of soils—defined as the capacity of a soil to host a large quantity and diversity of living organisms involved in its functioning and in the provision of ecosystem services—is currently questioned for viticultural systems. The biological quality of vineyard soils and the impact of viticultural practices are still poorly known. Although the number of studies on the subject is soaring on an international scale, to date a global review of all these studies is missing. Yet, such a summary is needed to (1) globally assess the impact of the different viticultural practices on all soil organisms, and (2) beyond the question of soil heritage, assess their consequences on the functions provided by soil organisms. In this context, we carried out the first-ever meta-analysis on the biological quality of vineyard soils by systematically inventorying the whole international academic literature issued in the last 30 years.

2. Materials and methods

Keywords and terminology of bibliographical search - The search was carried out in the Web of Science database with the following combination of keywords: *soil* AND *vineyards* AND (**bio** OR **diversity*) AND (*practice** OR *manage** OR *land use*). The biological groups were distributed into macrofauna, mesofauna, microfauna, and soil microorganisms (Maron and Ranjard 2019; Terrat and Djemiel 2019; Cortet and Hedde 2020). The measured parameters addressed 3 main properties of soil biological quality: the biological heritage, the functional state, and the sanitary state of the soils. The present review is focused on the following biological parameters, provided for each group when available: biomass, abundance, richness, activities (basal respiration, enzyme activities), functional genes and groups, and pathogen or pest occurrence.

Evaluation of the genericity of the results - A decision-making rule was chosen to evaluate the genericity of the results for each modality x biological parameter combination while taking the diversity of the experimental strategies implemented to study vineyard soil biological quality into account. This rule was based on 2 values, i.e., (1) the number of articles dealing with the combination, and (2) the total number of plots recorded in these same articles. These 2 numbers were multiplied to obtain a genericity value. Three classes of values were created: values ≤ 10 indicated non-generic results (1 or 2 articles and a low number of plots), 11 ≤ values ≤ 50 indicated low to medium genericity (one article dealing with a small network of plots), and values ≥ 51 corresponded to strong genericity (a large network of plots and/or several articles).

Bibliometric analysis – The results of 104 articles are exploited in this study. The first published studies about the effects of viticultural practices date back to 1995, but the publication rate has only been significant since 2017, and 40% of the articles published in the last 25 years were published in the last 3 years. The geographical distribution of the vine-growing sites studied in the 104 analyzed publications showed that most of the sites were located in Europe and North America. Fifty percent of the publications concerned only 3 European countries, i.e., Italy (24%), France (13.5%) and Spain (12.5%), while the USA ranked 4th with 9.6% of the publications. This ranking is in line with the ranking of wine-producing countries (OIV 2019).
Three types of experimental strategies were identified in the referenced articles: laboratory experiments under controlled conditions (1-2 sites), controlled experiments in situ (1-10 sites), and networks of plots. The results of most of the articles of the collection were obtained on 1 or 2 sites: 84% of the articles were based on experimental conditions including less than 10 sites, 15 articles or so included more than 10 sites, and only 4 included more than 50 sites.

3. Results and discussion

All the results presented below are taken from the article published in Environmental Chemistry Letters in 2020 (Karimi et al.). To access the literature used and summarized in this meta-analysis, please refer to this article.

3.1. *Biological quality of vineyard soils compared to other land uses.*

Vineyard soils were compared with soils from other land uses, i.e., forests, grasslands, crops, and orchards, for numerous parameters. Altogether, the biological quality of vineyard soils is lower than or equal to that of other soils, even though a few biological groups appear to be favored. Microbial and earthworm biomass are lower in vineyard soils, as well as fungal, nematode and micro-arthropod diversity. By contrast, total micro-arthropod abundance (collembola and acarids) is higher in vineyard soils than under the other land uses, and mycorrhiza are more abundant than in field crops.
This observation should be balanced by the fact that these soils are initially low productive soils in most cases. Grapevines are often planted when conditions are unfavorable to other crops. They have low nutrient and water requirements that allow them to develop on shallow, organic-matter-poor soils with a low available water capacity that display de facto a poorer biological quality.

3.2. *Biological quality of vineyard soils depends on the production system.*

Even if there exist numerous production systems in viticulture, only 3 of them—conventional, organic, biodynamic—are sufficiently documented in the literature to allow for comparisons. It is important to note that these systems differ by certain specific practices generally related to vine phytoprotection (pesticides, fungicides) and to the use of herbicides or mineral fertilizers, but other practices can be in common, such as the use of a cover or organic amendment inputs. For each production system, specifications can be interpreted or adapted in a highly variable way depending on the region and the pedo-climatic situation.
The impact of production system has been studied for all biological groups, but only the results on microorganisms, nematodes and earthworms present a good level of genericity. Microbial biomass, respiration, and microbial activity are higher in the soils under organic farming. Mycorrhiza are favored too, whereas pathogenic fungi are less present. Nematode abundance, together with micro-arthropod and arthropod abundance, tends to be higher under organic viticulture than under conventional viticulture. Biological diversity within all taxonomic groups is equivalent regardless of production system. Earthworm communities are the only ones to be negatively affected by organic and biodynamic viticulture, whether in biomass, total abundance or in the different ecological groups.
The enhancement of biological life in soils under organic viticulture can be explained by lower pesticide toxicity/persistence and the use of organic amendments. On the other hand, the negative impact observed on earthworms can be explained by more intense tillage, especially to replace herbicides by mechanical weeding.

3.3. Impact of viticultural practices on soil biological quality.

The viticultural practices likely to influence soil biological quality can be classified into 4 main themes, namely tillage, soil cover, fertilization, and phytosanitary treatments (Fig. 1). Grapevine protection (pesticides, fungicides) has been scarcely studied, in addition modalities vary across studies, and experimental doses are rarely realistic for a responsible agronomical use (e.g., for copper). Therefore, the present summary is more particularly focused on chemical weeding (herbicides).

Impact of tillage - The impact of tillage has been measured on microbial communities and on the macrofauna, but no reference has been found about the nematofauna or micro-arthropods. Inter-row tillage is usually compared with inter-row plant cover. Few details are provided about tillage depth, tools and intensity, as well few articles have been recorded about in-row tillage. Inter-row tillage induces a 20–45% loss of microbial biomass compared with a grass cover. Compared with a plant-covered soil, microbial respiration, mycorrhization rate and arthropod abundance and diversity are also lower. Bacterial and fungal diversity and earthworm communities do not appear to be disturbed, but these results lack genericity. While microorganism and

earthworm biomass and diversity are strongly reduced in the days and weeks following tillage, microbial activity and epi-anecic earthworm abundance are enhanced.
Inter-row tillage tends to degrade soil biological quality, and the effect is clearest as the tillage is more recent. Nevertheless, the impact is variable depending on biological groups. These results should be taken with care given their low level of genericity.
Impact of the soil cover – The presence of an inter-row plant cover, whether temporary or permanent, spontaneous or sown, enhances microbial biomass and diversity, but also nematode and earthworm abundance. Compared with bare soil, soil with a temporary plant cover can display a doubling of its microbial biomass and nematode abundance, while a permanent cover can multiply microbial biomass by 3 and nematode abundance by 4. Earthworms also respond favorably to in-row plant covers. Interrow plant covers tend to decrease fungal diversity compared with tilled soil. If the cover is sown, microbial diversity also tends to decrease compared with tilled soil. The amplitude of the effect of a sown cover on microbial activity and microbial and arthropod functional groups depends on its composition. By contrast, the composition of a sown cover has no effect on microbial biomass or respiration. Micro-arthropods and arthropods are not affected by the presence of a plant cover, whether it be temporary or permanent. The diversity and density of mycorrhizal fungi (AMF) are favored by a permanent and natural soil cover compared with chemical or mechanical weeding. Finally, mulching could favor arthropod and micro-arthropod abundance compared with a plant cover without impacting microbial biomass.
The practices aimed at maintaining a soil cover are globally beneficial to the soil biological quality and sanitary state. Whatever the cover modalities, the effect is either neutral or positive compared with tilled soil.

Impact of fertilization – Microbial biomass and bacterial diversity are similar whether organic fertilization is applied or not, but organic fertilization has a stimulating effect compared with mineral fertilization. Moreover, microbial activity and respiration as well as arthropod abundance and diversity tend to be enhanced by organic fertilization compared with mineral fertilization. Soil bacterial abundance is higher when organic fertilization is applied than when no fertilization is applied. Total nematode abundance and the abundance of the different nematode functional groups tends to be negatively impacted by organic fertilization compared with mineral fertilization, and parasitic nematodes tend to be favored. Addition of grapevine pruning wood, which is a local organic input, enhances soil microbial biomass, respiration and activity compared with mineral fertilizers or the absence of fertilizer input, and burying prunings has the same effect as leaving them on the surface. Biochar inputs do not seem to have any recognized effect on biological parameters.
Although organic fertilization tends to enhance soil life, it is hard to draw conclusions because the effects are highly variable depending on products, soils, and biological parameters (e.g., nematodes), and most of the results presented in this study lack genericity.

Impact of phytosanitary treatments: chemical weeding – Chemical weeding is mostly studied through the use of glyphosate. Microbial parameters (biomass, abundance, respiration, activity) do not differ under herbicide use compared with mechanical weeding. Earthworms appear to be favored by chemical weeding in terms of biomass and abundance compared with mechanical weeding, but their activity is affected. By contrast, herbicides have a strong deleterious effect on total nematode abundance and the different nematode functional groups, with twofold less nematodes than under mechanical weeding and threefold less than under grass cover mowing. Herbicides also have a noxious effect on mycorrhizal fungi.
Chemical weeding and the use of glyphosate have variable effects depending on the biological parameters. Although the topic of chemical weeding is often addressed in the literature, the ecotoxicological impact of only a small number of alternatives to glyphosate is tested.

4. Conclusions

Based on our meta-analysis, we can conclude that the use of a soil cover, whether it be plant or mulch, is a practice that enhances soil life. This practice appears to be consistent with an approach aimed at reducing the use of synthetic phytosanitary products. This reduction is favorable to soil biological quality, as suggested by the rather negative ecotoxicological effects of chemical weeding and the comparison of organic viticulture with conventional viticulture. By way of compensation, the organic farming usually includes mechanical weeding. Yet, all types of tillage appear to be unfavorable to soil life. Even if the effects of organic fertilizers strongly depend on local specificities (product type, soil type), their input is consistently more beneficial than the input of mineral fertilizers. Grapevine pruning wood are the only input with a clearly identified effect. This amendment, even if of local origin, is the only one to be common to all vineyards and easily accessible to all vine-growers. Thus, adding prunings to the soil instead of burning or exporting them constitutes an asset for improving soil biological quality. Other products can enhance soil life according to the soil type. Therefore, the rationale behind an input should be built and tested depending on product availability and local pedoclimatic constraints.

Although the research effort devoted to the biological quality of vineyard soils has intensified in the last 15 years or so, the currently acquired body of knowledge is not sufficient to conclude about the state of vineyard soils and all the associated practices in a robust and generic manner. Especially we identified the following unexplored themes: the impact of synthetic pesticides other than herbicides, the impact of copper at the currently applied doses in an organic viticulture context, the impact of the different fertilization types (organic vs. mineral) and of the different types of organic amendments, the impact of grapevine establishment techniques, and soil biodiversity as a biocontrol tool. Therefore, research must keep investing strongly in fundamental and finalized approaches in this field to integrate soil biological quality as a lever of the evolution of the wine-producing model toward greater environmental sustainability.

5. Acknowledgments

This study was supported within the framework of the Plan National Dépérissement du Vignoble (PNDV), thanks to financial support from the Comité National des Interprofessions des Vins (CNIV), the CASDAR and FranceAgriMer.

6. Litterature cited

The list of all the articles summarized in the meta-analysis can be provided on demand to the corresponding author.

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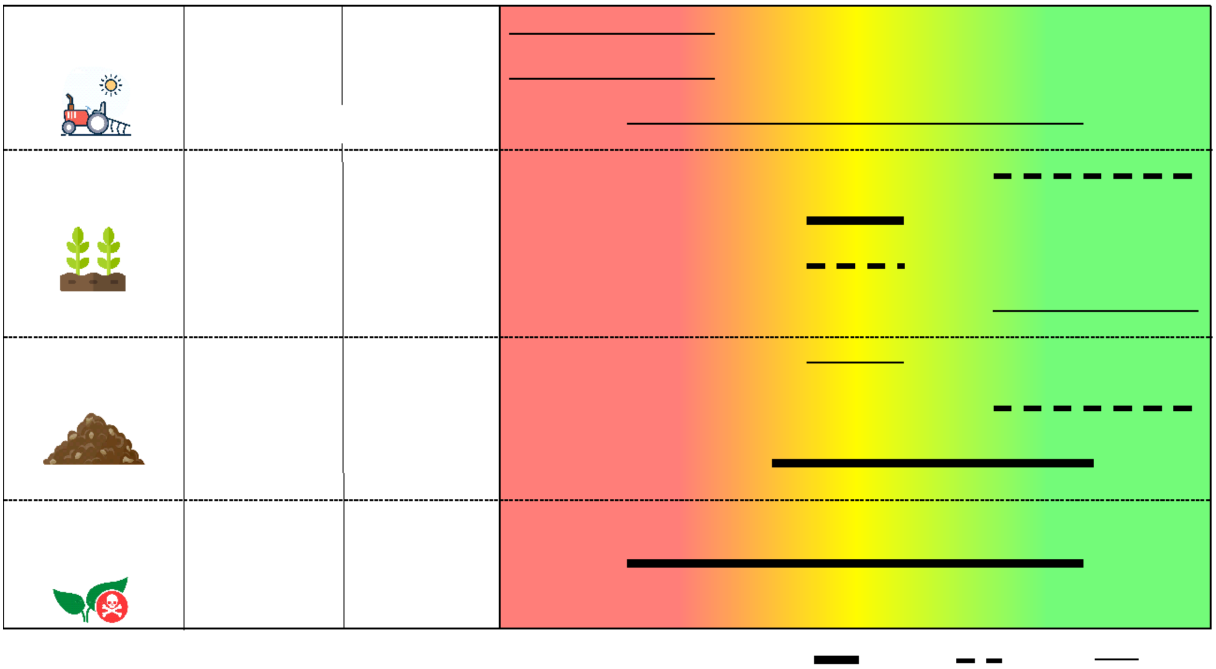

Figure 1: Overview of the impact of viticultural practices on soil biological quality.