IVES Technical Reviews vine & wine

terclimpro

https://doi.org/10.20870/IVES-TR.2025.8481

This article is published in cooperation with the 2nd edition of TerclimPro (18–19 February 2025), Bordeaux & Cognac, France.

A meta-analysis of the ecological impacts of viticultural practices on soil biodiversity

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Soil quality and adequate soil management are key levers for sustainable viticulture. Until now, a global and comprehensive analysis of the impact of viticultural practices on soil biodiversity was lacking. We conducted a meta-analysis of the international literature to rank viticultural production systems and practices according to their impact. Tillage, bare soil and mineral fertilisation are significantly deleterious to the whole soil biodiversity, whereas cover crops, organic fertilisers and pruning wood inputs are beneficial.

Material and methods

A search of the Web of Science database was carried out in 2020 using the following combination of keywords: *soil* AND *vineyards* AND (**bio** OR **diversity*) AND (*practice** OR *manage** OR *land use*). The keywords *practice**, *manage** and *land-use* of the search referred to production systems and practices, and were classified into 4 groups: land-use, method of production, practices, and temporal and spatial heterogeneity. The biological parameters were associated with the keywords *soil*, **bio**, and **diversity*. The biological groups categorised as macrofauna, mesofauna, microfauna, and soil microorganisms[1,2]. The review focused on the following biological parameters, which were provided for each group when available: biomass, abundance, richness, activities (basal respiration, enzyme activities), functional genes and groups, and pathogen or pest occurrence.

The genericity of the results for each production system/practice x biological parameter combination was evaluated based on the number of articles and the total number of plots studied.

Bibliometric analysis

The results of 104 articles were exploited. The first published studies about the effects of viticultural practices date back to 1995, but the publication rate is only significant as from 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 analysed publications showed that most of the sites were in Europe and North America. Fifty percent of the publications comprised only 3 European countries: Italy (24 %), France (13.5 %) and Spain (12.5 %); meanwhile, the USA ranked 4th with 9.6 % of the publications. This ranking is in line with that of wine-producing countries.

The results of most of the articles in the collection were obtained from one or two sites: 84 % of the articles were based on experimental conditions in less than 10 sites; meanwhile, the results of approximately 15 articles were obtained from more than 10 sites, and only those of four were obtained from more than 50 sites.

Biological quality of vineyard soils depends on the production system

The impacts of production systems have been studied for conventional viticulture, organic viticulture and biodynamics. For each production system, practices can greatly differ depending on the region and pedo-climatic situation.

Synthetic diagrams summarise the data for all biological groups (Figure 1). The position of the point on the radius indicates the effect of the studied treatment compared with a reference treatment, whose biological state is represented by the median black circle. Microbial biomass, respiration, and microbial activity are higher in the soils under organic farming. Mycorrhiza are also highly present, whereas pathogenic fungi are less present. Nematode abundance[3], 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 that are negatively affected by organic and biodynamic viticulture, whether in terms of biomass, total abundance or ecological groups.

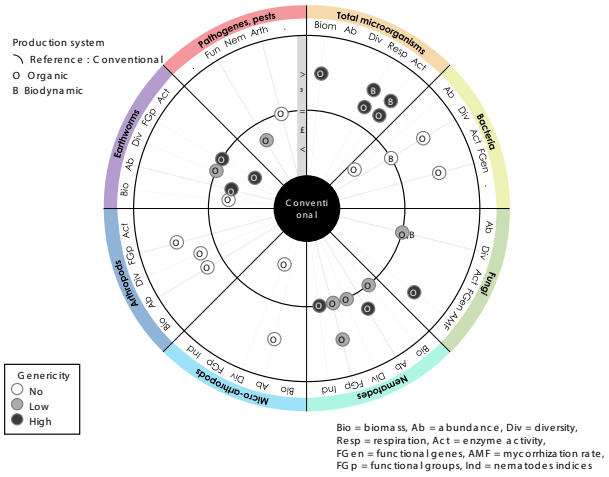

FIGURE 1. Comparison of soil biological quality among the different methods of viticultural production.

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 when mechanical weeding replaced herbicides.

Viticultural practices have a large impact on soil biology

The viticultural practices likely to influence soil biological quality can be divided into the four main study areas of tillage, soil cover, phytosanitary treatments and fertilisation, each of which involved several conditions variously documented in the literature. The present paper focuses specifically on the impact of soil cover.

Cover crop was the main soil cover studied; little information is available about the effect of mulching. An inter-row plant cover, whether temporary or permanent, spontaneous or sown, enhances microbial biomass and diversity, but also nematode and earthworm abundance. Compared to bare soil (Figure 2), soil with a temporary plant cover can display a doubling of its microbial biomass and nematode abundance, while a permanent cover can increase

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microbial biomass 3-fold and nematode abundance 4-fold[4]. Inter-row plant cover tends to decrease fungal diversity compared to tilled soil. If the cover is sown, microbial diversity also tends to decrease compared to tilled soil. The diversity and density of mycorrhizal fungi (AMF) increase with permanent and natural soil cover compared to chemical or mechanical weeding[5].

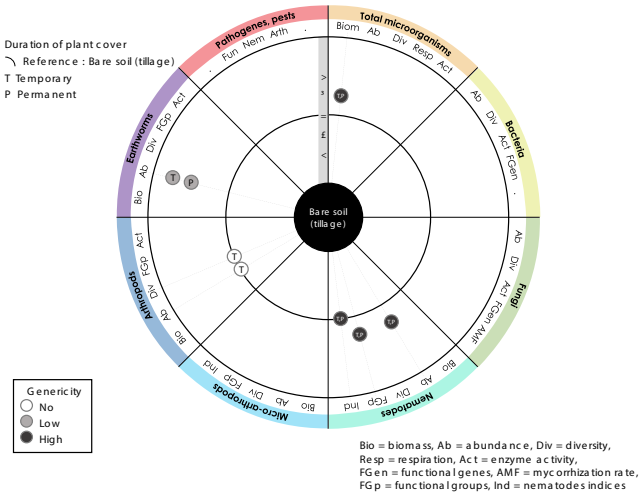

FIGURE 2. Impact of a temporary or permanent plant cover on soil biological quality.

Regarding the impact of mechanical versus chemical weeding, herbicides have variable effects depending on the biological parameter (Figure 3). Microbial parameters do not differ under herbicide use in contrast to mechanical weeding. Earthworm biomass and abundance appear to increase with chemical weeding relative to mechanical weeding, but earthworm activity is affected. By contrast, herbicides have a strong deleterious effect on total nematode abundance and the different nematode functional groups, with half the amount of nematodes compared to mechanical weeding. Herbicides also have a noxious effect on mycorrhizal fungi[6]. Although the topic of chemical weeding is often addressed in the literature, the ecotoxicological impact of only a small number of alternatives to glyphosate have been tested.

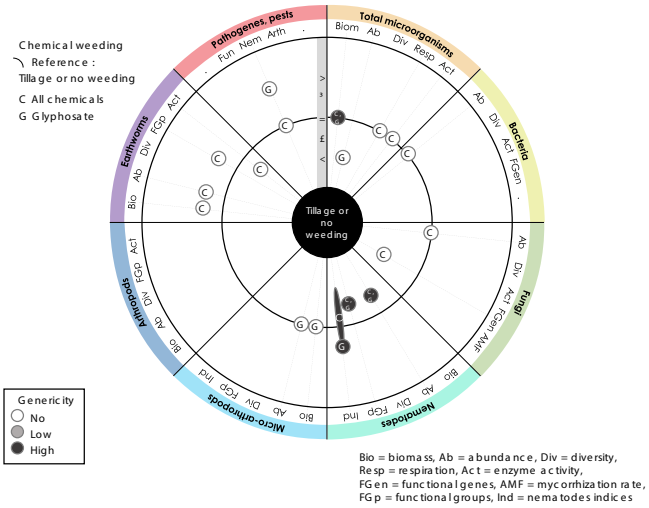

FIGURE 3. Impact of chemical weeding on soil biological quality.

Towards agroecological solutions for sustainable viticulture

Based on our meta-analysis (Figure 4), we can conclude that applying a soil cover, whether as plants or mulch, is a practice that enhances soil life. It allows the use of synthetic phytosanitary products to be reduced, thus enhancing soil biodiversity, as indicated by the rather negative ecotoxicological effects of chemical weeding and the results of comparisons of organic viticulture and conventional viticulture. Nevertheless, the organic farming usually includes mechanical weeding, a practice that always appears unfavorable to soil life. Though the effects of organic fertilisers strongly depend on specific local factors (e.g., product type and soil type), their application is consistently more beneficial than those of mineral fertilisers. Grapevine pruning woods are the only input with a clearly positive effect. Therefore, the rationale behind the use of a given input should be developed and tested taking into account product availability and local pedoclimatic constraints.

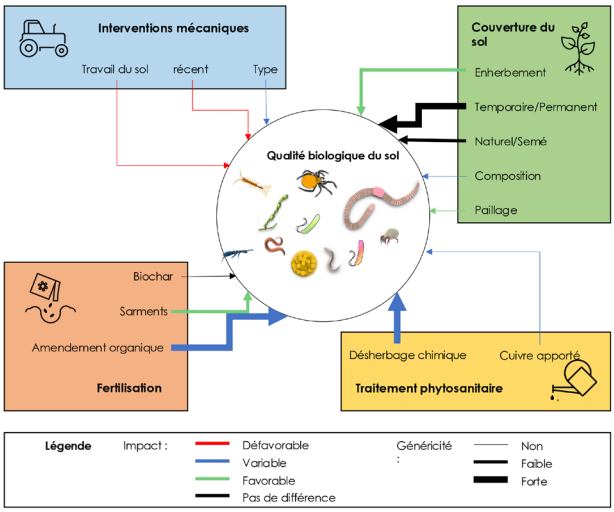

FIGURE 4. Overview of the impact of viticultural practices on soil biological quality.

Our work highlighted research fields that remain uninvestigated such as the impact of i) synthetic pesticides other than herbicides, ii) copper at currently applied doses, ii) different fertilisation and amendment types, iv) grapevine establishment techniques, v) herbicides other than glyphosate compared to tillage, and vi) biocontrol solutions. Therefore, research should continue to aim at developing fundamental and finalised approaches that integrate soil biological quality as a lever for shifting the wine-producing model towards greater environmental sustainability. ■

Acknowledgment: *this study was funded by the Plan National Dépérissement du Vignoble (PNDV) and the Comité National des Interprofessions des Vins (CNIV).*

Sources: *Article based on the research article 'A meta-analysis of the ecotoxicological impact of viticultural practices on soil biodiversity' (Environmental Chemistry Letters, 2020). https://doi.org/10.1007/s10311-020-01050-5*

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