Comment on 'Ecotoxicity of copper input and accumulation for soil biodiversity in vineyards' by Karimi et al. (2021)

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Gwenaël Imfeld[1] · Joëlle Duplay[1] · Sylvain Payraudeau[1]

Ecotoxicity studies of vineyard soils usually evaluate the effect of addition of a specific dose of copper (Cu). However, soil characteristics and the dynamics of Cu storage should also be considered to determine at the vineyard and -regional scales ecotoxicity thresholds for soil biological quality.

Karimi and coauthors recently wrote an enlightening review on Cu ecotoxicity on soil biodiversity in vineyards using results from a literature review (Karimi et al. 2021). This is particularly welcome in a context where wine growers, and in particular organic farmers, are confronted with the absence of efficient alternative to Cu against downy mildew and the future possibility of a Cu ban (Andrivon et al. 2018). The vine professional community is experiencing great pressure linked to the historical legacy of the Cu use, the fast evolution of regulations and climate change. To face this challenging interplay, novel paradigms and integrative approaches are urgently needed, throughout Europe, but taking local specificities into account, to meet the requirements of sustainable viticulture. Only this may help prevent an inexorable increase of Cu in soils through its systematic and massive use.

Karimi and coauthors reach the conclusion that the currently authorized dose for grape production in the EU, i.e., a maximum of 28 kg Cu ha^{-1} over 7 years, has no deleterious effects on soil organisms. They also compare the average annual dose of 4 kg Cu ha^{-1} a^{-1} to a Cu ecotoxicity threshold of 200 kg Cu ha^{-1} a^{-1} defined from a thorough meta-analysis of available data. Although this threshold may be conservative, such a dose specification is, in our view, insufficient to guarantee the integrity of soil fertility and biodiversity. We believe that, if accepted, such a view may hamper current efforts to reduce the use of Cu and attempts to develop locally-accepted alternatives to Cu. Indeed, Cu storage and availability in the soil prior to the addition of a new dose of Cu may strongly vary at the vineyard scale and across Europe depending on soil physicochemical properties, the vegetation and the various pools of Cu formed in soil. The Cu speciation varying according to soil conditions challenges the notion of harmless use of Cu at a specific dose, albeit lower than typical historical applications. We define Cu speciation as the identification and quantification of the different Cu species, forms or defined phases in which Cu is present in the soil. Cu speciation depends on the mineralogy and chemistry of the soil.

As emphasized by Karimi and coauthors, historical accumulation of Cu has already resulted in levels above the defined Cu ecotoxicity threshold of 200 kg Cu ha^{-1} in some European vineyard soils. This implies to consider not only local risks associated with the historical use of Cu, including soil pH, vegetation, redox or organic matter content, but also risks of present and future use of Cu in agriculture. Recognizing such historical and present risks is not only necessary, it also affords an opportunity to stimulate studies and innovation for sustainable viticulture. In our view, it is urgently needed to define locally toxicity risks for organisms and integrative approaches of cultivation practice to limit Cu accumulation (Cesco et al. 2021). Considering the distribution of Cu concentration by types of land use, vineyards represent the type of land use with the highest proportion (14.6%) of soil samples with Cu levels above 100 mg kg^{-1} (Ballabio et al. 2018). Every Cu input to the soil contributes to gradual accumulation in the vineyard soil since Cu does not degrade and Cu export at the European scale is two orders of magnitude less than the net accumulation of Cu. Considering to use 4 kg Cu ha^{-1} a^{-1} simply means that the Cu ecotoxicological threshold for soil biological quality may be reached within 25 years in many vineyards across Europe.

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Thus, Cu accumulation in soil poses a practical and immediate agricultural and environmental threat at the European scale because the Cu ecotoxicological threshold for soil biological quality may be reached in the coming decades, thereby challenging vineyard sustainability. In conventional viticulture, the risk of Cu exposure and toxicity in soil and related aquatic ecosystems combined with that of synthetic organic fungicides has not received much attention. Moreover, it is unclear whether the restriction to a maximum application rate of 28 kg Cu ha^{-1} over seven years will be sufficient to address this issue over time. In a recent study, we showed that the Cu concentration in vineyard soils is on average > 30% higher than geogenic and atmospheric non-agricultural anthropogenic Cu (Droz et al. 2021). We estimate that the threshold of 100 mg Cu kg^{-1} (about 150–250 kg Cu ha^{-1} in the top 10–15 cm layer of soil) has already been exceeded for about 70% of the vineyard areas in central Western Europe. This proportion will increase in the next decades. Thus, it is necessary to predict Cu accumulation in vineyard soil across Europe considering the local risks and history of Cu use. In the future, the proportion of European vineyard area exceeding the predicted no-effect concentration (PNEC) values, typically ranging from 30 to 290 mg Cu kg^{-1} depending on soil properties, may vary widely depending on the Cu dose (Droz et al. 2021). Assuming constant soil properties, the use of 8, 4 or 2 kg Cu ha^{-1} a^{-1} is expected to increase, respectively, by at least 94%, 2% or 0.5% the proportion of vineyard areas exceeding the PNEC in the next 100 years. These predictions support the idea that Cu use according to current EU regulation, i.e. 28 kg Cu ha^{-1} a^{-1} over 7 years, may substantially reduce the ecotoxicological impact of Cu in the European vineyards compared to historical application doses. However, it also emphasizes that the level of environmental risk for soil biological quality may be substantial at some locations, and also increase in the next decades.

Cu is partly immobilized in soil with various Cu pools coexisting and evolving over space and time. It is thus crucial to consider Cu speciation and its subsequent bioavailability as well as the factors controlling it, in order to evaluate its ecotoxicological impact on soil biological quality. Ecotoxicological studies are often carried out without the consideration of the chemical and physical distribution of historical Cu among soil fractions, especially in vegetated soil (Ruyters et al. 2013). The pool of Cu stored in the soil is not an inert, non-reactive mass as opposed to a labile, reactive and potentially harmful input of freshly applied Cu (e.g., Tom-Petersen et al. 2004). For instance, availability and associated toxicity of Cu increase with decreasing soil pH, especially at pH below 5.5. Although soil organic matter rapidly immobilizes Cu, the diffusion of freshly applied Cu into soil metal oxides, clay minerals and precipitated carbonates is slow and gradual (Lock and Janssen 2003). This results in different chemical fractions of Cu in the soil that can be mobilized depending on hydro-climatic and soil conditions. Hence, retention processes and availability of aged Cu in the soil components are dynamic and vary according to the type of soil.

The availability and mobility of Cu in soil also depend on the vegetation. The Cu biogeochemical cycle in the soil–plant system diverges from that of the non-rooted bulk soil (Shabbir et al. 2020). Root-induced changes of the pH and rhizosphere organic compounds in annual grass and perennial plants like grapevine control the Cu speciation and the formation of soluble organometallic complexes in the soil, altering the potential of Cu toxicity (Brunetto et al. 2016). In addition, long-term impacts of repeated application of Cu on both taxonomic and functional diversity of macro- and micro-organisms of vineyard soils require more detailed studies of the dynamics of the Cu availability and dissemination of Cu resistance determinants by horizontal gene transfer. Crucially, recurrent intra- and inter-annual application of Cu to vineyard soil may promote both Cu and antibiotic resistance, because these two traits are intimately related and can be transferred across the bacterial domain (Cesco et al. 2021). Hence, it cannot be excluded that current use of Cu in vineyards contributes to development and dissemination of the concomitant Cu- and antibiotic-resistance via cross-resistance mechanisms.

Altogether, the use of Cu up to 28 kg Cu ha^{-1} over seven years according to current regulation can significantly reduce the detrimental impact of Cu on human health and ecosystem diversity. However, it may not always imply an improvement of the quality and sustainability of grape production across Europe. The variability in content, aging and mobility of historical Cu accumulated in soil should be carefully evaluated at the vineyard and the regional scales. This will allow to define the local use and assess the impact of Cu more specifically to shape holistic approaches to reduce the Cu toxicity and consider the trajectory of Cu accumulation in soil. Despite the scientific interest of the review by Karimi and coauthors, and the fact that it proposes numerous research avenues to respond to the lack of scientific knowledge on the impact of Cu in wine-growing soils, there is a risk that some of the conclusions are relayed to the agricultural world without integrating the nuances mentioned here. This motivates the present comments.

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Declaration

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