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Copper ecotoxicity in French vineyard soils

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How toxic is copper contamination of vineyard soils to the ecosystem? That is the thorny question this paper seeks to answer. Based on studies describing Cu toxicity in plants, it points out that Cu contamination of vineyard soils is generally moderate and that demonstrations of Cu ecotoxicity at plot level are rare. It stresses that Cu ecotoxicity depends above all on its bioavailability in the soil and explains why it also appears in calcareous soils. Lastly, it identifies priorities for further research in this field.

Significant but often moderate contamination

In France, the median Cu concentration measured in the surface horizon (0–20 cm) of vineyard soils is between 50 and 100 mg/kg[1] [2]. This median value reflects the moderate Cu contamination of most vineyard soils compared with Cu-polluted soils (from industry or mining) where Cu concentrations often exceed 1000 mg/kg[3]. However, behind this moderate median lies a high variability in Cu contamination levels from one vineyard soil to another. In some historic vineyards, Cu concentrations can vary more than 10-fold between plots and exceed 500 mg/kg^{-1} in the most contaminated plots[4]. As is to be expected, the level of Cu contamination in vineyard soils is closely linked to the number of years Cu-based fungicides have been used, and thus to the age of the plot (Figure 1). The issue of Cu ecotoxicity is thus of most concern in the oldest vineyard plots.

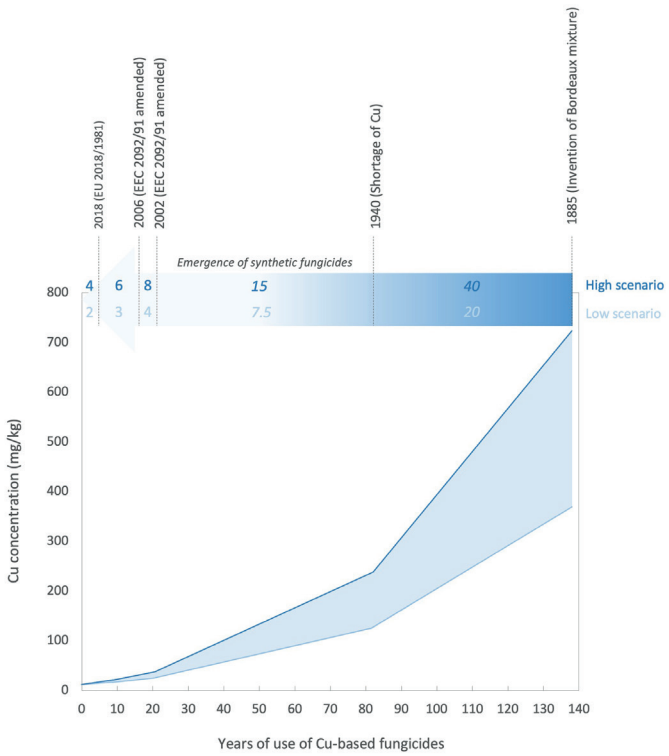

FIGURE 1. Simulated change in Cu concentration in the surface horizon (0–20 cm) of vineyard soils as a function of the number of years Cu-based fungicides have been used. Year 0 is 2023.

Cu ecotoxicity is rarely demonstrated at plot level

For reasons that may be related to its well-known fungicidal properties and/or the severity of its effects at high doses (disruption of cell enzyme function and plasma membrane integrity), Cu is often cited as the cause when dieback is observed in the vineyard. However, demonstrations of copper toxicity at plot level are rare and, as far as we know, are limited to two contexts in France: the sandy acid soils (pH<5) of Bordeaux, where excess Cu caused vine dieback on planting in the 1960s[5]; and the calcareous soils of the Languedoc (southern France), where excess Cu inhibited the growth of durum wheat sown after vines were grubbed up in the 2000s[6]. Several reasons may explain why Cu ecotoxicity at plot level is so rare. The first is that Cu does not accumulate to extremely high concentrations in most French vineyard soils. This explanation may be linked to the fact that soil organisms have means of defense against Cu (exudation, detoxification), giving them a certain tolerance to the metal[7] [8]. A second reason is that Cu ecotoxicity is difficult to detect in the field, as visual symptoms of copper toxicity, notably leaf chlorosis, are not very sensitive to Cu. Added to this is the fact that vine roots rapidly dig below the surface horizon, which is where Cu accumulates. The visual symptoms of Cu toxicity are thus to be found in young vines or inter-row plant cover, through a change in their root architecture, for example: reduced elongation and thickening, and/or excessive branching.

Cu ecotoxicity depends on its bioavailability

The ecotoxic effect of Cu depends not just on the total Cu content of the soil, but above all on its bioavailability. Bioavailability is the degree to which chemicals present in the soil may be taken up or metabolized by biological receptors (ISO 17402). In soil, Cu is distributed between the solid phase and the soil solution. As in the case of plants, the soil solution is assumed to be the main compartment from which soil organisms extract Cu (Figure 2). Cu present in the soil solution thus exhibits greater bioavailability and hence ecotoxicity than that included in the mineral structure, for example. Because Cu is present at low concentrations in the soil solution (namely 10^{-3} to 10^{-6} g/L^{-1} depending on the soil and environmental conditions), its availability from the solid phase, i.e. its solubility, is a key parameter for assessing its bioavailability. Cu, like other elements, is taken up in soil solution in the form of the Cu^{2+} ion, hence its speciation in soil solution is a second parameter to consider when assessing its bioavailability. Soil pH, and to a lesser extent the organic matter (OM) content, are the two physical-chemical parameters with the greatest influence on Cu bioavailability. Both influence the solubility of Cu and its speciation in solution. Generally speaking, Cu bioavailability is higher in soils with a clearly acid pH (pH<6) and a low OM content (<1%), as was the case in some Bordeaux vineyard soils in the 1960s. In contrast, good management of pH (>6.5) and OM content (>2%) helps to contain the bioavailability and ecotoxicity of Cu in soils. Ideally, management of Cu ecotoxicity is based on measuring its bioavailability in the soil, to identify areas or plots at risk of Cu toxicity, and to assess the effectiveness of corrective practices.

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Cu bioavailability is traditionally assessed using soil extraction in the presence of EDTA (NF X31-120), although the predictive value of this extraction in terms of Cu bioavailability leaves room for improvement. In addition, as this indicator was originally developed to detect the risk of trace element deficiency in crops, it seeks to reproduce an exposure pattern based on taking up elements in solution. As such, it is probably not valid for organisms that ingest soil directly, such as earthworms.

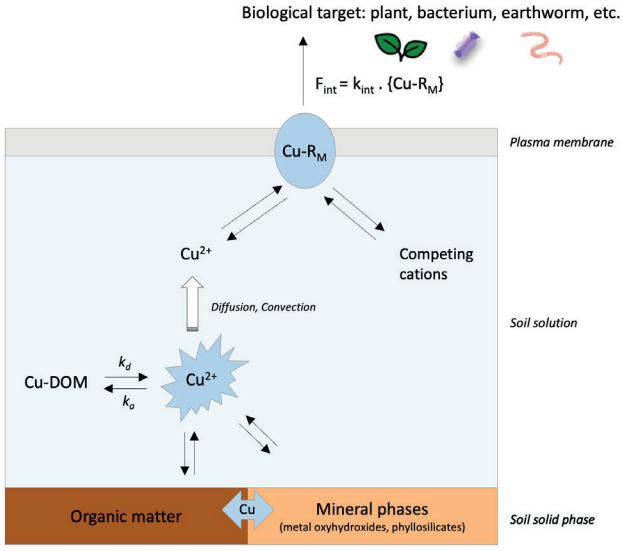

FIGURE 2. Conceptual model of soil organism exposure to copper, inspired by the free ion model that is the benchmark for plants. DOM: dissolved organic matter, R_M: membrane receptor.

Cu ecotoxicity is also found in calcareous soil

Paradoxically, it is in calcareous soils that the effects of Cu are most often seen on crops, where Cu bioavailability should be low in principle due to the high pH. The best-known example is the Languedoc vineyard, where the wine crisis led to vines being grubbed up and replaced by other crops, notably durum wheat. Durum wheat shows yellowing indicative of iron chlorosis specifically when planted on limestone plots with high Cu concentration (Figure 3). This finding established a link, now confirmed, between Cu contamination of soils and Fe deficiency in crops.

This induced Fe deficiency is most often observed in cereals, suggesting that excess Cu disrupts Fe acquisition, which for grasses is based on production of phytosiderophores. The underlying assumption is that for soils with low Fe bioavailability, typically calcareous soils, Cu diverts phytosiderophores from their initial Fe-complexing function.



FIGURE 3. Symptoms of copper toxicity in durum wheat observed on a calcareous soil previously planted with vines (Hérault, France) (photo credit: A. Michaud, M. Bravin, P. Hinsinger, INRAe Montpellier).

This potentially increased sensitivity of Fe-deficient organisms to copper toxicity illustrates that Cu ecotoxicity depends not only on Cu bioavailability in the soil, but also on the bioavailability of other elements with which it interacts, such as Fe. On another note, this Cu/Fe antagonism means that liming of non-calcareous vineyards soils should be carefully managed, to avoid inducing too pronounced a drop in Fe bioavailability in the surface horizon.

Conclusion

While it seems essential to look for effective, sustainable alternatives to Cu to combat downy mildew in grapevines, it is important to remember that Cu ecotoxicity in vineyard soils is rare. Conversely, no study has shown that this copper contamination of French vineyard soils, albeit moderate, is without effect on vine physiology and the long-term future of viticultural agroecosystems. It would thus seem useful to conduct further research on this subject. This might include monitoring the medium-term effect of Cu doses similar to those used in vineyards on a range of targets and traits, to allow a precise assessment of the biological quality of soils. It is also important to stress that Cu ecotoxicity depends not only on the total Cu content of the soil, but also on the soil characteristics that determine its bioavailability. It thus seems necessary to provide the wine-growing sector with more robust indicators of Cu bioavailability than EDTA extraction, to allow better understanding of the risk of Cu ecotoxicity in vineyard soils. ■

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