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Interception of copper-based fungicides by cover crops: a way to prevent soil contamination in vineyards?

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The use of copper (Cu) fungicides in viticulture has led to the accumulation of Cu in vineyard topsoils, threatening soil health and the sustainability of vineyard ecosystems. This study examines the potential of cover crops as "umbrella" plants to intercept Cu from Cu fungicides before it reaches the soil, and investigates the mechanisms by which Cu might be retained by leaves exposed to these fungicides.

Materials and Methods

Experiment 1 was designed to evaluate the potential of cover crops (CCs) to intercept copper from Cu fungicides. Six cover crops that can be grown under the rows in vineyards due to their low water and nutrient requirements—*Herniaria glabra, Lippia nodiflora, Sedum album 'Coral Carpet', Trifolium fragiferum,* and *Sedum kamtschaticum* (Figure 1)—were grown on 1 m² microplots at the INRAE site in Villenave d'Ornon (Gironde, France) and were sprayed repeatedly (n = 12) with either Cu hydroxide (Kocide flow®) or Bordeaux mixture (BB-RSR disperss®). These two forms of Cu are currently the most widely used in viticulture and might exhibit contrasting Cu "solubilities"[1]. Following the final treatment, the coverage rate of the different cover crops was assessed using the Canopeo® software, and the fraction of Cu intercepted by CCs was calculated from their coverage rate, their biomass density, and the final concentration of Cu in their shoots. The methods used in Experiment 1 are detailed in the attached document (https://ives-technicalreviews.eu/article/view/10074/53263).

Experiment 2 was designed to determine the mechanisms of Cu retention and internalisation in leaves treated with Cu fungicides. It was conducted on germinated grapevines to ensure that the leaves were homogeneous in terms of age and in background Cu. Seeds of *Vitis vinifera* subsp. sylvestris were germinated and grown until the ten-leaf stage. At this stage, 3 drops of $CuSO_4$ or deionised water (control) were deposited on the abaxial side of the 6th and the 7th leaves. The plants were then grown for a further seven days before µXRF leaf mapping and µXANES Cu speciation analyses were performed on cross-sections of the treated leaves. The methods used in Experiment 2 are detailed in the original article.

Results and Discussion

1. Cover crops intercepted up to 11 % of Cu sprayed with copper fungicides

At harvest, the average coverage rate ranged from 29 % for *Sedum kamtschaticum* to 77 % for *Herniaria glabra* (Figure 1), with no significant difference between the two Cu fungicides tested. The concentration of Cu in the shoots increased ($p < 0.05$) in all CCs following the application of Cu fungicide, in similar proportions among CCs, but in contrasting proportions between the two Cu fungicides tested (Figure 2a). For all CCs except *Trifolium fragiferum*, the Cu concentration in the shoots was approximately twice as high ($p < 0.05$) in plants treated with Bordeaux mixture compared to those treated with Cu hydroxide. This result contrasts with some studies conducted on grapevines[2], which show little difference in leaching between different forms of Cu. In plants sprayed with Cu fungicides, the concentration of Cu in the shoots was always greater than 30 µg g^{-1}, often exceeding 100 µg g^{-1}, which is the minimum concentration required for the valorisation of their biomass in ecocatalysis[3 4]. Such a concentration of Cu in shoots has very rarely been observed in plants with no harm to their growth[5], except in some Cu hyperaccumulators (e.g., *Haumaniastrum* spp.)[6]. This confirms the hypothesis that the excess Cu in the shoots of treated plants was due to the interception of the Cu contained in Cu fungicides and suggests that in leaves sprayed with Cu fungicides, Cu is stored in locations (tissues, cellular organelles) and/or in forms that do not disrupt the physiology of the plant.

Figure 2b shows that CCs intercepted between 2 % and 6 % of the Cu sprayed as Cu hydroxide, and between 2 % and 11 % of the Cu sprayed as Bordeaux mixture. This corresponds to an amount of Cu intercepted ranging from 0.08 to 0.44 kg ha^{-1} for an annual input of 4 kg Cu ha^{-1}, which is more than the amount of Cu exported by phytoextraction[7 8]. Although this result should be interpreted with caution, as the Cu fungicides were not sprayed onto grapevines but directly onto the cover crops, it suggests that growing CCs under the row is a complementary option for reducing Cu accumulation in vineyard soils. Figure 2b also shows that the fraction of Cu intercepted can vary among cover crops. For example, *Herniaria glabra* intercepted 3 to 6 times more Cu than *Trifolium fragiferum,* depending on the fungicide tested, even though their coverage rates were similar (Figure 1). CCs therefore appear to have varying abilities to fix Cu, likely related to some characteristics of their leaves (e.g., cuticle thickness, wax composition, trichome density, and/or stomatal density).

2. Localisation and speciation of Cu in grapevine leaf exposed to $CuSO_4$

µXRF distribution maps showed higher accumulation of Cu in the spongy parenchyma and in the vasculature of the leaves exposed to $CuSO_4$ than in the controls (Figure 3). This suggests that some of the Cu deposited at the leaf surface via $CuSO_4$ drops was internalised in the grapevine leaf after 7 days. µXRF distribution maps also showed sulfur (S) accumulation hotspots specific to the leaves exposed to $CuSO_4$, in locations similar to those of Cu (Figure 3). The speciation results indicate that this is likely due to in-plant chelation of Cu by sulfur ligands. Indeed, the µXANES analyses presented in the original article show that the average spectrum collected in Cu hotspots, particularly in the vasculature, was satisfactorily reproduced by 100 % Cu-glutathione complex. The change in Cu speciation from free Cu ions in the drops of $CuSO_4$ to Cu complexes in the Cu accumulation hotspots inside the leaf suggests activation of plant detoxification mechanisms in response to Cu stress in $CuSO_4$-treated leaves[9 10].

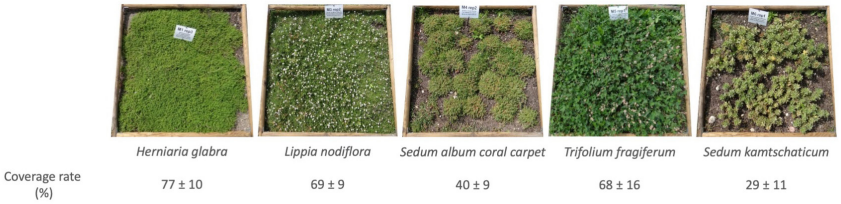

FIGURE 1. Photo of each cover crop tested and its associated average coverage rate (source: Canopeo®), on the day of the last application of Cu fungicide.

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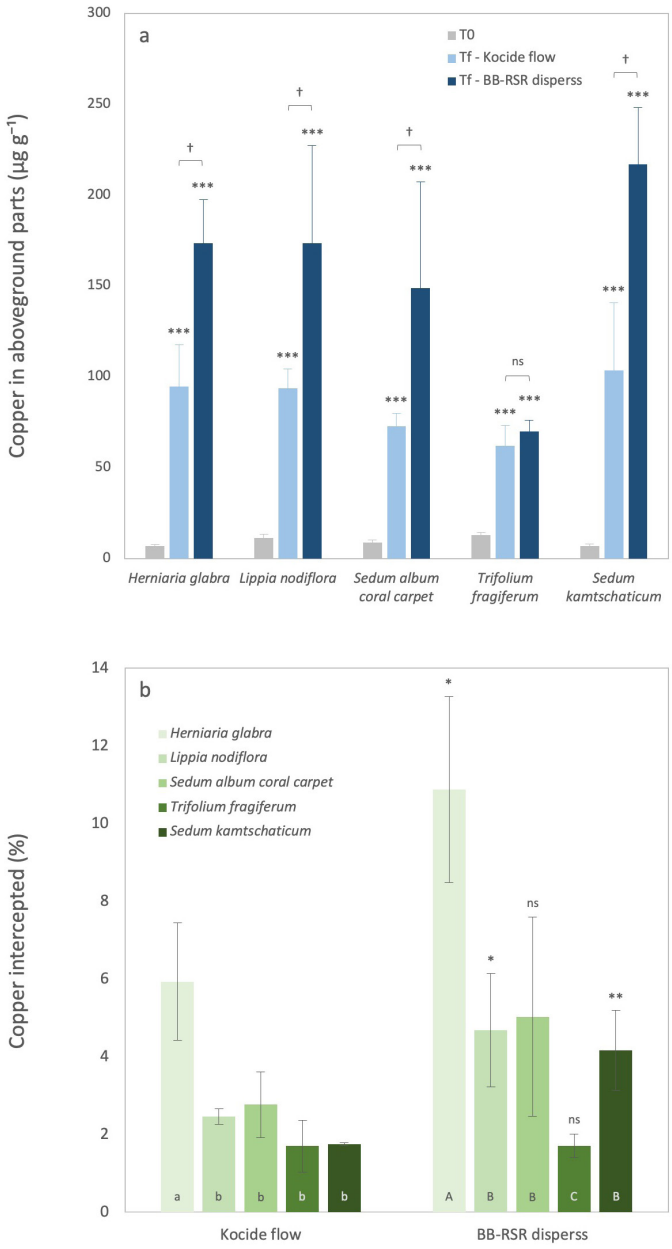

FIGURE 2. Concentration of Cu in the shoots of cover crops before the first application (T0) and after the twelfth and final application of Cu fungicide (Tf) (a), and fraction of Cu sprayed with Cu fungicides intercepted by cover crops (b).
Six cover crops were sprayed with either Cu hydroxide (Kocide Flow®) or Bordeaux mixture (BB-RSR Disperss®) according to the treatment schedule presented in Table T1 (https://ives-technicalreviews.eu/article/view/10074/53263). In (a), for a given cover crop and a given Cu fungicide, *** indicates that the concentration of Cu at Tf differed significantly from that at T0, at a probability level of $p < 0.001$; and for a given cover crop, † indicates that the concentration of Cu at Tf differed significantly between the two fungicides tested, at a probability level of $p < 0.05$. In (b), for a given cover crop, * and ** indicate that the fraction of Cu intercepted differed significantly between the two fungicides tested, at a probability level of $p < 0.05$ and $p < 0.01$, respectively; and for a given Cu fungicide, mean values with different letters (lowercase letters for Kocide flow®, uppercase letters for BB-RSR disperss®) indicate a significant difference in Cu interception ($p < 0.05$) among cover crops. In (a) and (b), data are mean values ± one standard deviation. ns: not significant.

Conclusion

This study proposes growing cover crops under the row as a complementary mitigation measure to limit the environmental impact of Cu fungicides in viticulture. To this end, *Herniaria glabra* is a potentially good candidate as it grows rapidly, has low water and nutrient requirements to avoid competition with grapevine, and can intercept up to 11 % of Cu when sprayed as Bordeaux mixture. This concept of "umbrella" plants remains to be validated under more realistic grapevine treatment scenarios than those tested in Exp. 1, notably when Cu fungicides are applied to the grapevine canopy, and cover crops receive only drift, wash-off and throughfall. Ideally, this "umbrella" role played by cover crops during the grapevine treatment period would complement the functions performed by winter

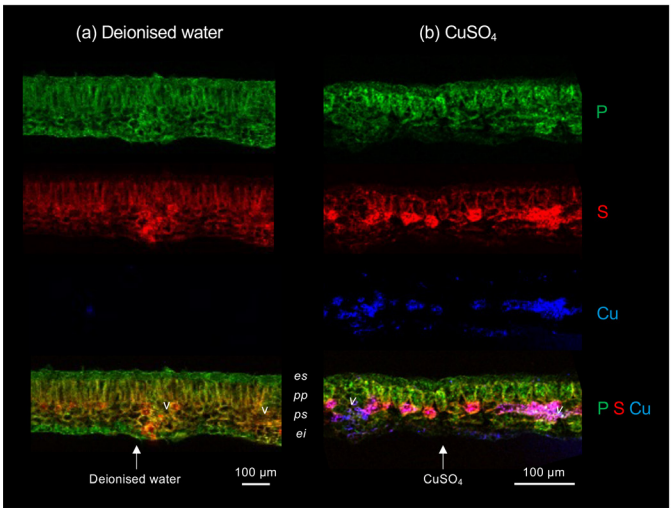

FIGURE 3. Synchrotron µXRF tricolour distribution maps of P-S-Cu in a cross-section of grapevine leaf (*Vitis vinifera* subsp. sylvestris) exposed to drops of either deionised water (a) or $CuSO_4$ (b).
Arrows indicate which side of the leaf was exposed to either deionised water or $CuSO_4$. *es*: upper epidermis; *pp*: palisade parenchyma; *ps*: spongy parenchyma; *ei*: lower epidermis; *v*: vasculature.

cover crops in terms of carbon sequestration, nitrogen fertilisation, and soil structure improvement. ■

Source: Sourced from the research article: "Interception of copper fungicides by cover crops as a way to prevent soil contamination in vineyards?" (Journal of Environmental Management, 2026).

Additional information regarding Experiment 1 is available here: https://ives-technicalreviews.eu/article/view/10074/53263. This supplementary material was used to evaluate and validate the data from this experiment, which has not been published in a peer-reviewed scientific journal.

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