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Evaluation of the dynamics and impact of nanomagnetites (Fe_3O_4) on lettuce (*Lactuca sativa*) in a context of cadmium contaminated soil

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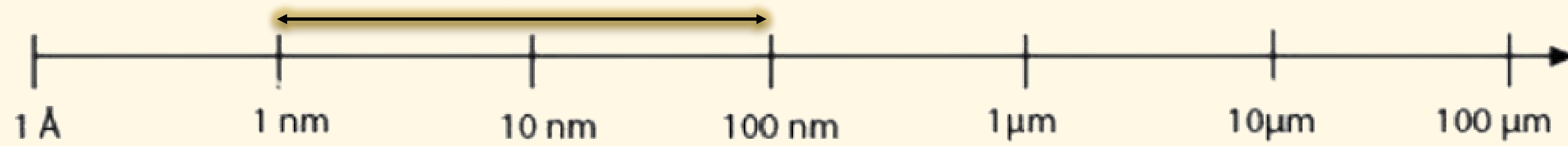
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CONTEXT OF THE STUDY

Human activities have led to the increasing release of trace metals (TMs) into the environment, leading to sanitary problems and disruption of ecosystems. Cadmium (Cd) pollution is an environmental concern all over the world because it is a non-essential metal with harmful effects on human health, animals, and plants.¹ Over the last few decades, around 22,000 tonnes of Cd have been released into the environment worldwide. Since many soils are contaminated with Cd, it seems essential to find a way of remediating soils in a controlled manner. For soil remediation, several approaches have been tested. Due to their physico-chemical properties and nanometric size, nanoparticles have been receiving substantial growing attention.² Among these nanoparticles, nanomagnetites (Fe_3O_4 , NPs-Fe) have great potential for soil remediation. Evaluating the impact and fate of these nanoparticles therefore seems essential notably for their use in phytoremediation (soil remediation by plants).

Nanoparticles



“Nanoparticles are particles with three dimensions smaller than 100 nm”

MATERIALS AND METHODS

To evaluate the effect of nanomagnetites (NPs-Fe) on lettuce (*Lactuca sativa*, var. golden yellow gotte) and their potential role as an adjuvant to improve the phytoextraction efficiency of Cd in soil, NPs-Fe were applied (1.2 g kg^{-1} soil) to a Cd contaminated soil (20 mg kg^{-1} soil). Nanomagnetites were synthesized by the iron salt co-precipitation method³ (using $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ and $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) under aerobic conditions and Cd was applied in the form of an aqueous solution of $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$.

Four modalities were tested and different analyses were performed on lettuce plants (6 plants per modality, mean \pm SEM) after 46 days of exposure to the treatments:

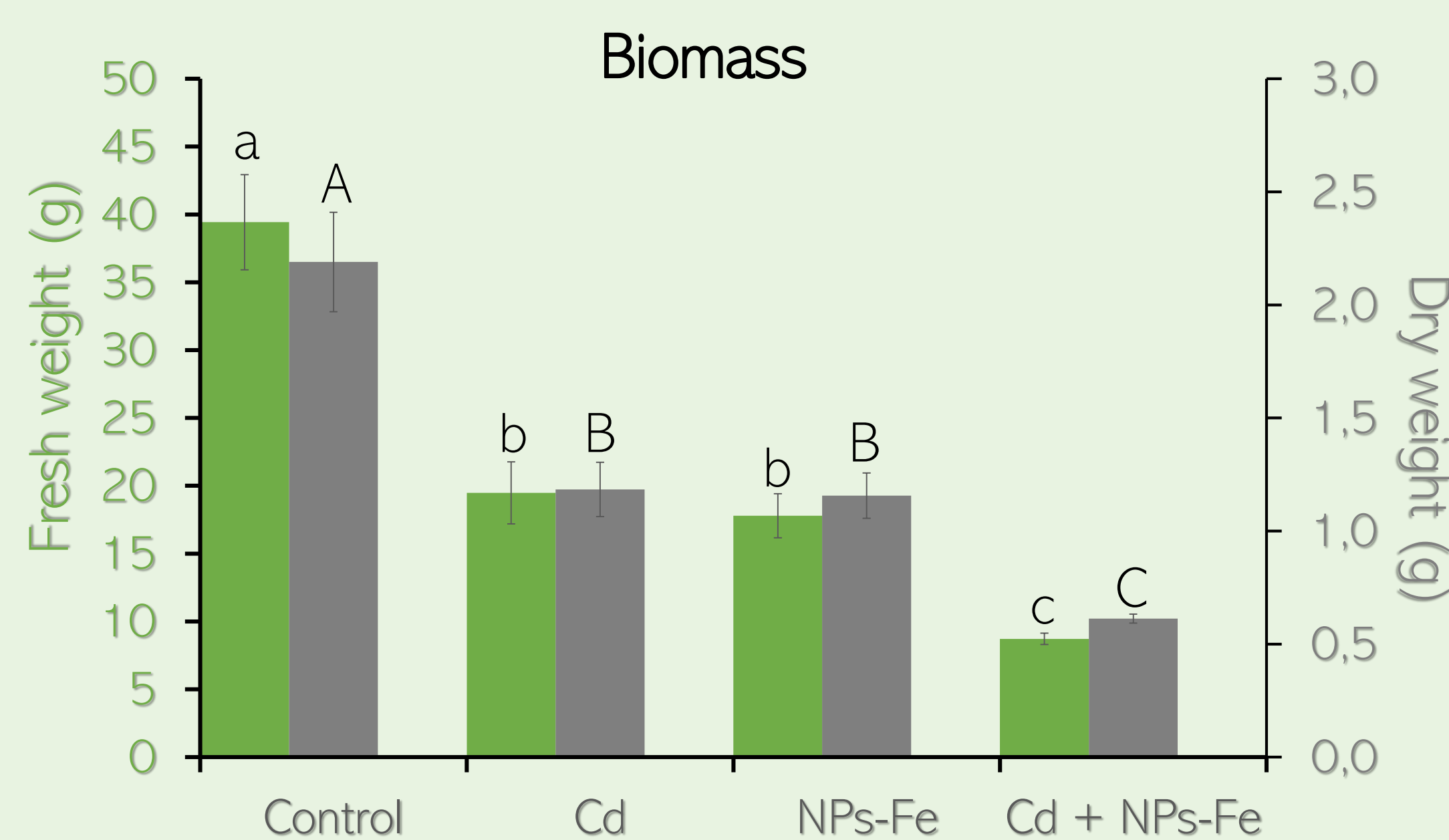
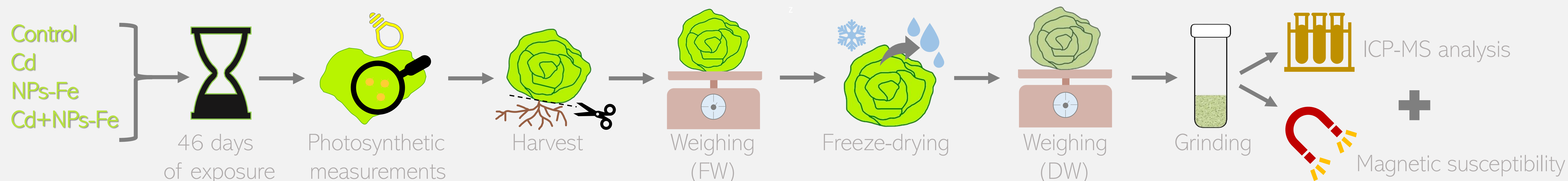
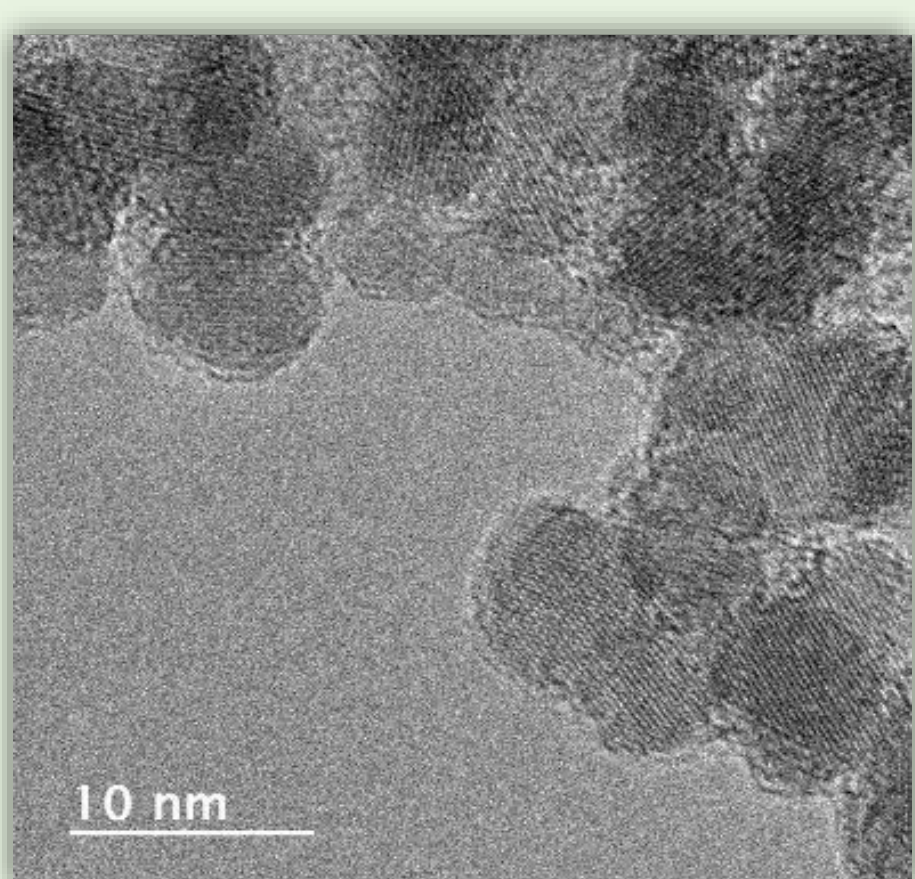


Fig. 1: Fresh and dry weight (g) of leaves of lettuce measured after 46 days of growth in control soil or soil containing Cd, NPs-Fe or Cd+NPs-Fe. Different letters indicate significant differences between treatments (p -value < 0.05).

The results show a negative impact of Cd and NPs-Fe on lettuce development, with a reduction in biomass of around 50% for each individual treatment (Cd and NPs-Fe) and over 70% for the Cd+NPs-Fe combined treatment, both for fresh (FW) and dry weight (DW).



Analysis shows that the synthesized nanomagnetites exhibited a round crystalline shape with a diameter of $9 \pm 2 \text{ nm}$.

Fig 4 : High-Resolution Transmission Electron Microscopy (HR-MET) observation of synthesized nanomagnetites (NPs-Fe).

RESULTS

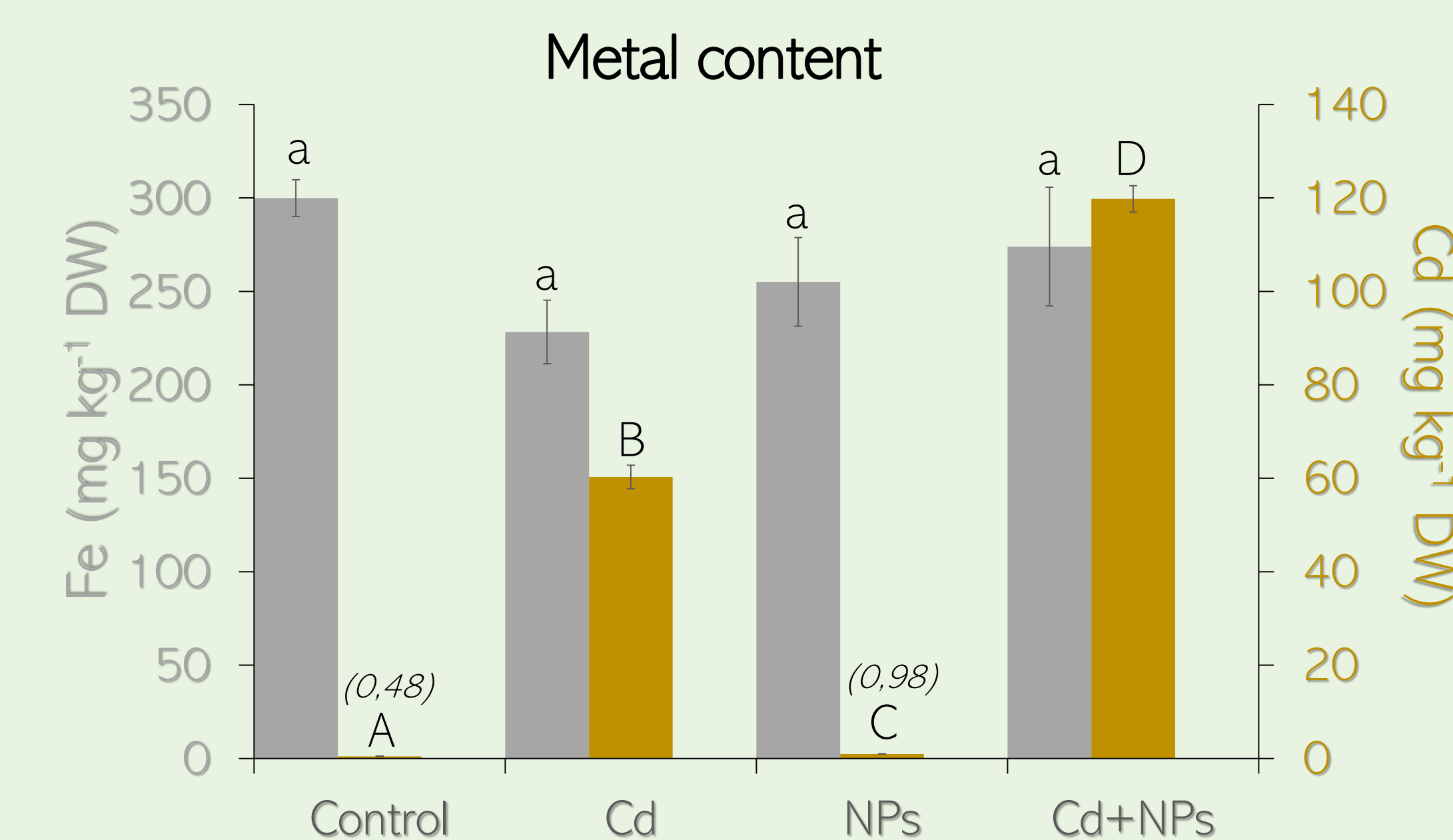


Fig. 2: Iron (Fe) and cadmium (Cd) concentrations (mg kg^{-1} DW) in lettuce leaves measured by ICP-MS after 46 days of growth in control soil or soil containing Cd, NPs-Fe or Cd+NPs-Fe. Different letters indicate significant differences between treatments (p -value < 0.05).

While the analyses do not show any difference in Fe content between the 4 treatments, a significant difference is observed for plant Cd content, which is 2-fold higher under NPs-Fe treatments (NPs-Fe and Cd+NPs-Fe) compared to nanomagnetites-untreated conditions (Control and Cd).

Table I. Nanomagnetite concentration (mg kg^{-1} DW) in dry leaves of lettuce calculated from magnetic susceptibility measurements after 46 days of exposure to NPs-Fe treatments.

Treatment	mg NPs-Fe kg ⁻¹ DW plant
NPs-Fe	52.74 ± 8.37
Cd+NPs-Fe	38.18 ± 6.67

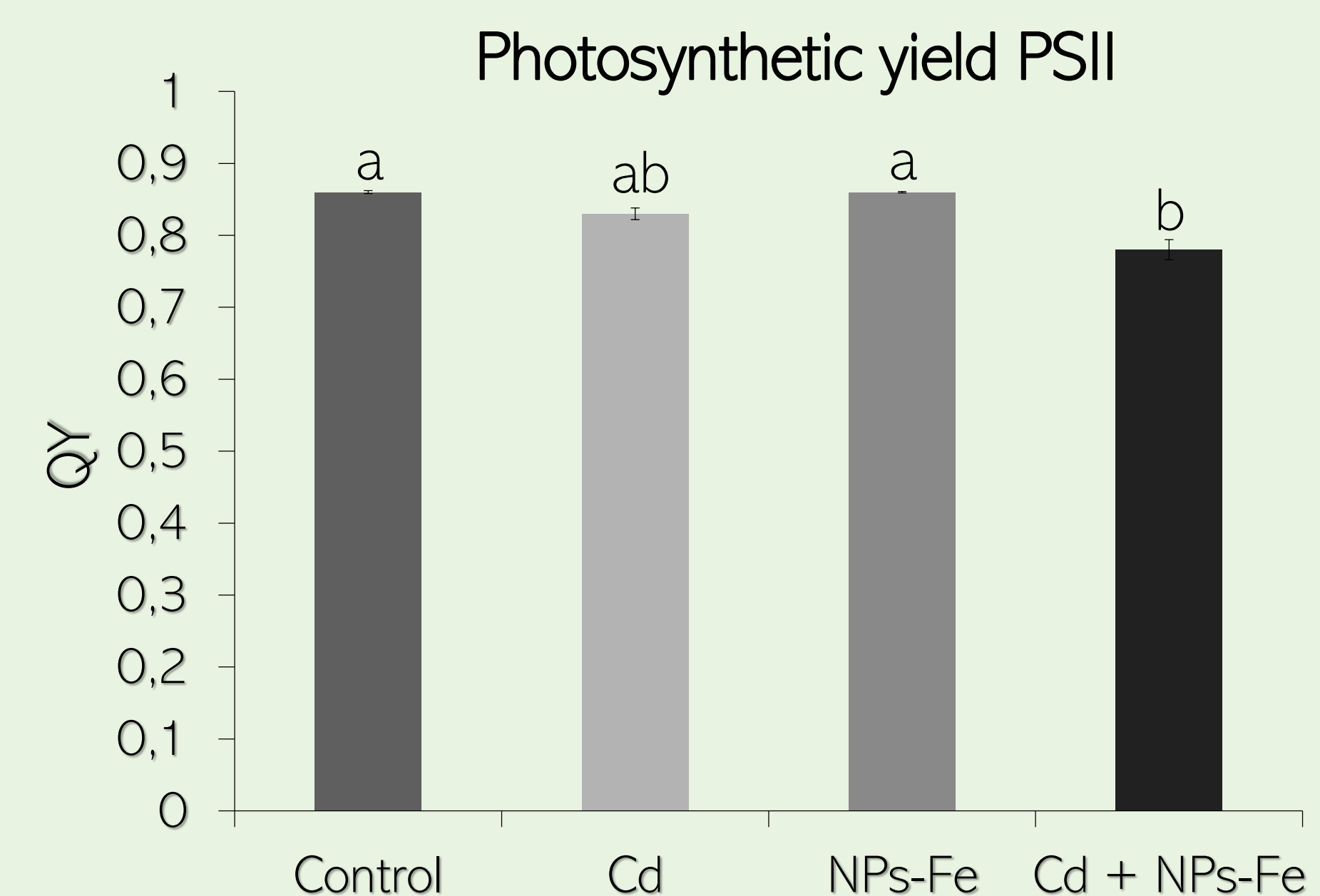


Fig. 3: Quantum yield (QY) of lettuce leaves measured after 46 days of growth in control soil or soil containing Cd, NPs-Fe or Cd+NPs-Fe. The measurements were taken just before harvesting. Different letters indicate significant differences between treatments (p -value < 0.05).

Concerning the photosynthetic yield, a significant difference is only observed between Control and Cd+NPs-Fe, with a small decrease of the QY, but remains fairly high.

A magnetic signal is detected in plants treated with NPs-Fe (with or without Cd), indicating the presence of NPs-Fe in plant tissues.

DISCUSSION AND CONCLUSION

This study showed that at the concentrations tested, NPs-Fe and Cd have a negative impact on the growth of lettuce plants. However, NPs-Fe significantly increase Cd concentration in plant tissues (2-fold higher when NPs-Fe are added in soil). This highlights that NPs-Fe can allow to increase the uptake of Cd from soil to plant and thus could be interesting for phytoremediation applications. In addition, this study confirms that *Lactuca sativa* is a Cd hyperaccumulator ($> 100 \mu\text{g g}^{-1}$ DW). The reduction of biomass of plants under all the tested treatments compared to control can be explained by Cd contamination of soils but also by oxidative stress induced by NPs-Fe (data not shown). The results also revealed that NPs-Fe could penetrate lettuce tissues since a magnetic signal was detected in plants treated with NPs-Fe. Further studies could be of interest to investigate the penetration pathways of NPs-Fe into the plant and to study the effect of NPs-Fe concentration on plant growth.

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