Sagardoy R, Morales F, López-Millán A-F, Abadía A and Abadía J.

Department of Plant Nutrition, Aula Dei Experimental Station (CSIC), Apdo. 13034, E-50080 Zaragoza, Spain.

INTRODUCTION

Zinc is essential for cell physiological processes, has no redox activities but plays structural and/or catalytic roles in many processes, and it is the only metal present in all enzyme classes [1,9]. When present at high concentrations and low pH Zn could be toxic, and plants affected may show symptoms similar to those found in other heavy metal toxicities such as those of Cd or Pb [3,4]. The mechanisms controlling Zn homeostasis in plants are still not fully known [2,5,6]. In contaminated and acid soils some crops may suffer Zn toxicity, and species that have a high Zn uptake capacity, such as spinach and beet, could be more sensitive to its excess [2,3]. Bioaccumulation of trace metals in plant tissues may present a health risk to wildlife and to humans [8].

MATERIALS AND METHODS

Plant culture. Sugar beet (*Beta vulgaris* L. cv Orbis) was grown in a growth chamber with a PPFD of 350 µmol m^{-2} s^{-1}, 80% RH and a photoperiod of 16 h, 23ºC/8 h, 18ºC day/night regime, in half-strength Hoagland nutrient solution with 45 µM Fe(III)-EDTA and different concentrations of Zn. Plants were used for measurements 9-12 days after imposing the high Zn treatments.

Pigments analysis. Leaf samples were collected and photosynthetic pigments extracted and quantified by HPLC [7].

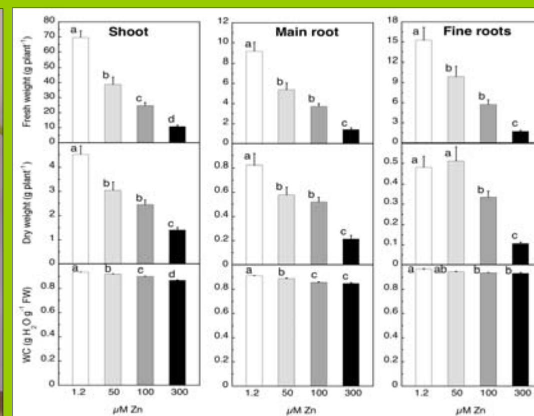
Gas exchange measurements. Measurements were made on attached leaves in the growth chamber with a portable gas exchange system (CIRAS-1, PP Systems, Herts, U.K.).

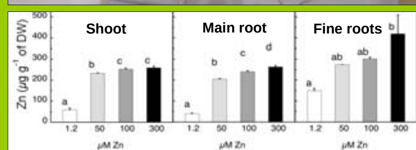
Statistical analysis. A LSD Bonferroni's test was performed on all data sets with SPSS 14.0 software. Columns marked with the same letter are not significantly different at the p≤0.05 probability level.

$[Zn]_{solution}$	Zn^{2+}	Zn[EDTA]	$ZnSO_4$(aq)
1.2 µM	86.0	7.5	5.8
50 µM	91.2	1.9	6.0
100 µM	91.7	1.4	6.0
300 µM	92.9	0.2	6.0

Table 1. Major Zn chemical species in the nutrient solutions, in percentage of the total Zn present, estimated *in silico* with the software MINTEQA2.

GROWTH PARAMETERS AND ZINC DISTRIBUTION

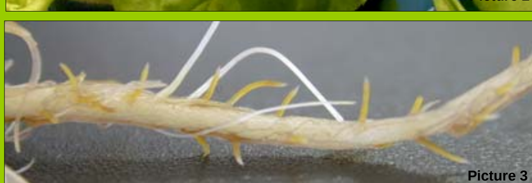




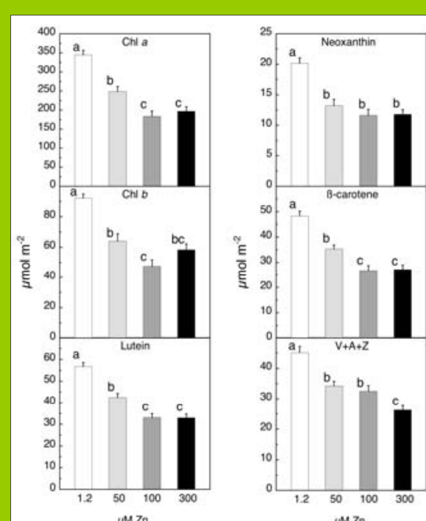
Top figure. Fresh and dry mass (in g per plant) and water content (in g g^{-1} FW) of shoots, main roots and fine roots of sugar beet plants grown with different Zn. Data are means ± SE (4 different batches of plants, 4-8 replications in each batch).

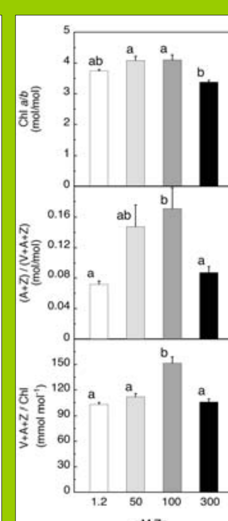
Picture 1 and figure. Comparative between control plant and 50, 100 and 300µM Zn treatment plants. Analysis of Zn concentration (ppm) in different parts on the plants.

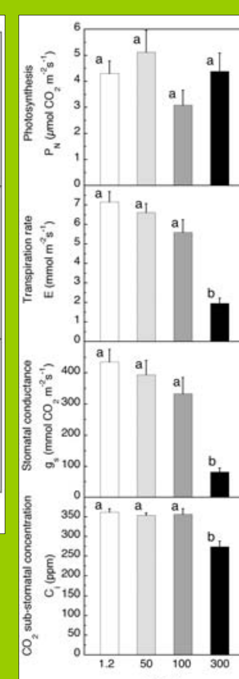
GAS EXCHANGE AND PIGMENTS ANALYSIS



Pictures 2 and 3. Chlorotic leaves and yellow root tips, symptoms of iron deficiency, on 50 and 100 µM Zn treatments.







Top figures. Leaf concentrations of photosynthetic pigments (carotenoids and chlorophylls, in µmol m^{-2}) and ratios (A+Z)/(V+A+Z) (in mol/mol), (V+A+Z)/Chl (in mmol/mol) and Chl *a*/Chl *b* (in mol/mol).

Right figure. Gas exchange parameters. Incident PPFD was between 130 and 170 µmol m^{-2} s^{-1}. Data are means ± SE (20 or more replications per treatment).

CONCLUSIONS

- Excess Zn reduced plant growth, and leaves showed chlorosis symptoms and signs of damage. Effects were also apparent in roots, with depressed growth and yellow tips at intermediate Zn concentrations and browning at highest one. Effects on gas exchange and photosynthetic pigments were markedly different depending on the Zn concentration in the nutrient solution.
- Our results indicate that Zn homeostasis is tightly controlled in sugar beet, since when Zn concentration in the nutrient solution increased (from 50 to 300 µM Zn) Zn shoot concentrations only increased marginally, from 236 to 259 µg g^{-1} DW, and Zn allocation to the shoot was little changed. Therefore sugar beet can be used as good model plant to study Zn homeostasis in plants.

References

(1)Barak and Helmke, (1993). The chemistry of zinc. In: A.D. Robson (Ed). *Zinc in soil and plants*. Kluwer Academic Publishers: Dordrecht, the Netherlands: 1-13.
(2)Broadley *et al.*, (2007). New Phytol 173: 677-702.
(3)Chaney, (1993). Zinc phytotoxicity. In: A.D. Robson (Ed). *Zinc in soil and plants*. Kluwer Academic Publishers: Dordrecht, the Netherlands: 135-150.
(4)Foy *et al.*, (1978). Ann Rev Plant Physio 29: 511-566.
(5)Hacisalihoglu *et al.*, (2004). Planta 218: 704-711.
(6)Kramer *et al.*, (2007). FEBS Lett 581: 2263-2272.
(7)Larbi *et al.*, (2004).Photosynth Res 79: 59-69.
(8)Singh and Agrawal, (2007). Chemosphere 67: 2229-2240.
(9)Vallee and Auld, (1990). Biochemistry 29: 5647-5659.

This work was supported by grants AGL2004-00194 and AGL2007-61948 to J.A. R.S. was supported by an I3P pre-doctoral fellowship from the CSIC.