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Preliminary Study on Mercury Uptake by *Rosmarinus officinalis L.* (Rosemary) in a Mining Area (Mt. Amiata, Italy)

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Among the different plants analyzed to assess environmental mercury contamination of mining areas, lichens are those most studied (Bargagli et al. 1987), followed by brooms (Barghigiani and Bargagli 1987) together with pine, which was also used in other areas (Lodenius and Laaksovirta 1979; Barghigiani and Bargagli 1987; Barghigiani et al. 1991a), and spruce (Barghigiani and Bauleo 1992). Other species, both naturally occurring and cultivated, have also been studied (Lindberg et al. 1979; Huckabee et al. 1983; Bombace et al. 1973; Barghigiani and Ristori 1994).

This work reports on the results of mercury uptake and accumulation in rosemary (*Rosmarinus officinalis L.*) in relation to metal concentrations in both air and soil.

R. officinalis is a widespread endemic Mediterranean evergreen shrub, which in Italy grows naturally and is also cultivated as a culinary herb.

This research was carried out in Tuscany (Italy), in the Mt. Amiata area, which is characterized by the presence of cinnabar (HgS) deposits and has been used for mercury extraction and smelting from Etruscan times (8th-1st century B.C.) until 1980 (Bombace et al. 1983), and in the country near the town of Pisa, 140 km away from Mt. Amiata.

MATERIALS AND METHODS

Ten sampling stations (Fig. 1) were chosen, seven on Mt. Amiata, in locations with different environmental Hg contamination levels which had been assessed previously (Breder and Flucth 1984; Barghigiani and Bargagli 1987; Ferrara et al. 1991; Barghigiani et al. 1991a; Barghigiani and Bauleo 1992), and three near

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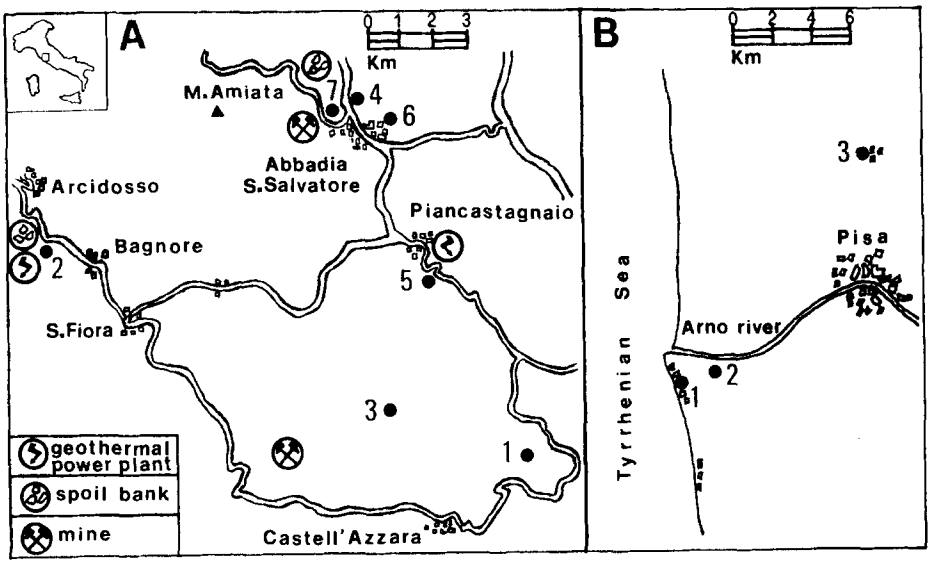

Figure 1. Mt. Amiata (A) and Pisa (B) sampling areas, and locations of the sampling stations.

Pisa for comparison. The features of the stations are described below.

Mt. Amiata
Station 1: 6.5 km from the Siele mine.
Station 2: 0.5 km from the smelting plant of Bagnore.
Station 3: 7 km away from one of the Piancastagnaio geothermal power plants and 3 km from the old mine of Siele.
Station 4: about 1 km from the mine of Abbadia.
Station 5: 800 m from the geothermal power plant of Piancastagnaio.
Station 6: Abbadia S. Salvatore, 2 km south-east of the mine and smelting plant and a large spoil bank of roasted cinnabar reforested 18 years ago.
Station 7: near the Abbadia plant.

Pisa
Station 1: 10 km from Pisa, near the sea.
Station 2: 8 km from Pisa, in the country, 500 m from a major motorway.
Station 3: 7 km from Pisa, in the country.

Samplings were performed between September and December 1992. At each station, three pools of 5 g of leaves were collected from three to five plants each together with three pools of three to five samples of soil (0-30 cm depth). The soil was carefully separated from impurities such as plant residues and gravels.
Of each pool, 0.2-0.3 g was mineralized with HNO_3 in a

Milestone MLS 1200 microwave digestion system and analyzed for Hg by cold vapour atomic absorption spectrophotometry (AAS), using a Perkin Elmer 50B mercury analyzer system (detection limit 5 ng Hg). The dry weight was determined on subsamples by bringing them to constant weight at 60°C in an oven.

The analytical procedures were tested using Reference Materials BCR 62 (olive leaves: 0.280±0.02 ppm Hg) and BCR 141 (calcareous loam soil: 56.8±4.3 ppb Hg) from the Community Bureau of Reference (Belgium). The recoveries were 98±4% (n=5) for BCR 62 and 96±5% (n=5) for BCR 141, analyzed in the same run as the environmental samples.

At each station 3 measurements of atmospheric Hg were performed. The air mercury was sampled for 24 hours by gold amalgamators arranged in a series of three traps each and connected to battery-driven pumps having a flow of 1 L/min. Mercury was released from the gold amalgam by heating the trap to 600°C and measured by AAS. The whole procedure is described in detail elsewhere (Barghigiani et al. 1991b).

ANOVA analysis and **t** test were used for the statistic elaboration.

RESULTS AND DISCUSSION

The results are reported in Table 1. On Mt. Amiata, plants and soil displayed a wide range of Hg

Table 1. Mercury concentrations in plants and soil ($\mu g/g$ dry weight) and in air (ng/m^3) at the different sampling stations. Averages ±SD are reported.

Station	Rosemary	Soil	Air
Mt. Amiata			
1	0.044±0.009	1.689±0.533	10.4±5.0
2	0.046±0.007	0.205±0.009	14.8±1.4
3	0.058±0.016	0.608±0.015	8.8±0.9
4	0.083±0.027	8.885±1.014	10.8±1.9
5	0.115±0.015	0.288±0.037	35.9±4.7
6	0.302±0.084	16.762±1.353	11.1±2.3
7	0.839±0.115	27.950±0.390	11.8±1.4
Pisa			
1	0.009±0.002	0.102±0.007	10.3±3.5
2	0.008±0.001	0.063±0.007	14.3±3.1
3	0.008±0.002	0.026±0.002	7.6±1.7

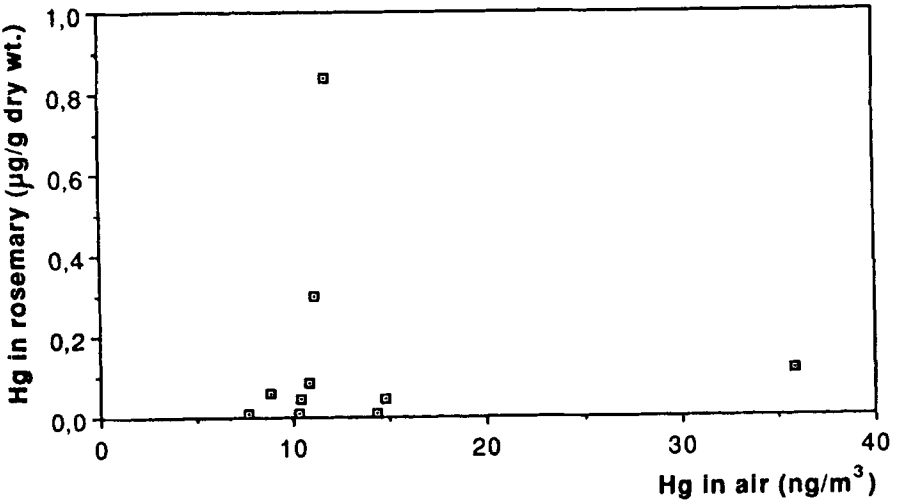

Figure 2. Average Hg contents in plants vs. air.

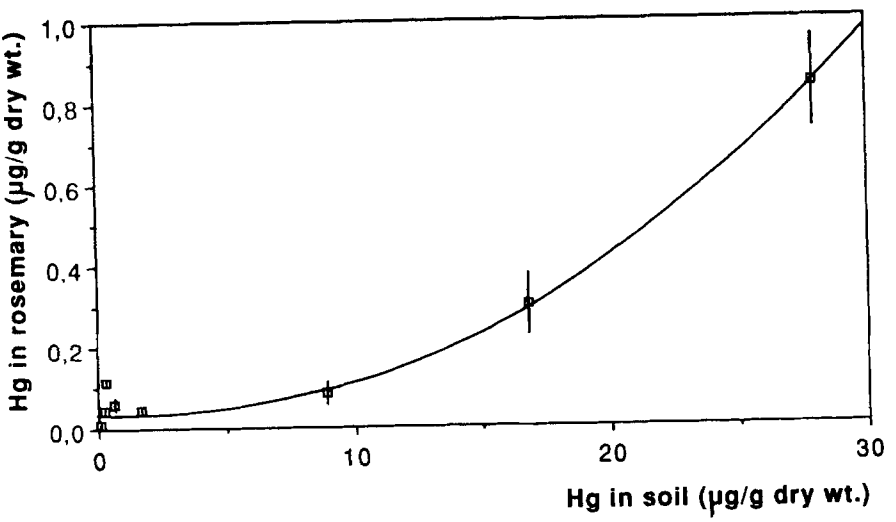

Figure 3. Relationship between average Hg concentrations in plants and in soil. The standard deviations from the average Hg values in the plants are shown.

concentrations. In particular, the highest Hg comcentrations were found around the Hg mine of Abbadia S. Salvatore (stations 4, 6 and 7), which was the largest plant and the last to close, in 1980. The lowest values were measured in the country near Pisa. The air mercury concentrations were not

significantly different between the various stations in the two areas except for station 5 near the geothermal power plant of Piancastagnaio. Both station 2 on Mt. Amiata and station 2 near Pisa displayed values slightly higher than the other stations, probably due to their closeness to the geothermal power plant and to the road, respectively.

Plotting the Hg concentrations in rosemary plants versus those in the air (Fig. 2) and soil (Fig. 3), no relationship was observed between mercury in air and in plants. By contrast, a significant relationship was observed between plants and soil. This indicates that in this plant, in the studied range of soil mercury concentrations, the Hg accumulation rate increased with increasing metal concentration in the soil. The quadratic relationship between plant and soil Hg concentrations, $y=0.03483+0.00102x^2$ ($R^2=0.9798$, parameter Std. Err.= 0.01282, 0.00005), was the best model, on the ANOVA basis, to express the accumulation trend of mercury in rosemary. The **t** test both on the intercept and on the quadratic coefficient gave a significance level greater than 95%.

It is commonly accepted that plants take up mercury both from the soil and from the atmosphere (Lindberg et al. 1979; Siegel and Siegel 1979; Huckabee et al. 1983; Barghigiani and Bargagli 1987; Barghigiani et al. 1991a).

Our results suggest that mercury concentration in rosemary on Mt. Amiata, where Hg concentrations in the soil are high, is mainly affected by soil contamination. This is also supported by the fact that at the three stations around Pisa, the plants had low Hg contrations even if the air had the same level of contamination as in the mining area. Only station 5 suggests mercury uptake from air. However, if we consider another closely studied plant in this area, *Pinus spp*, the relation between needles and air was found to be significant only in a range of air Hg concentration from about 10 to 600 ng/m^3, while at lower concentration ranges it was not (Barghigiani et al. 1991a).

The observed accumulation trend (Fig. 3) could have different explanations. One is that as the total mercury concentration in soil increases, the organic Hg compounds would increase more than the inorganic fraction. Indeed, organic Hg compounds are the most available forms of mercury to vegetation, being readily taken up by plants, due to their small degree of dissociation and adsorbability by humus and clays (Kabata-Pendias and Pendias 1985). The trend of the

curve should be due to the soil sorption, adsorption and buffering capacities towards mercury. It might also be dependent on the induction of metal-binding polypeptides, since many plant species synthesize phytochelatins upon exposure to Hg (Grill et al. 1987). Lastly, above a certain concentration threshold, Hg might affect the biochemical processes responsible for Hg release from the stomata, a detoxification mechanism observed in vascular plants by Kama and Siegel (1979). It must be pointed out, however, that mercury is phytotoxic (Siegel and Siegel 1979), but the plants analyzed did not display any evidence of toxic manifestations.

The use of rosemary as a biomonitor in a mining area like the one studied by us, with high Hg levels in soil and homogeneous concentrations in air, is possible for monitoring soil contamination but more problematic for atmospheric monitoring.

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