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Accumulation of Heavy Metals in Vegetables Grown in an Industrial Area in Relation to Soil

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Contamination of the biosphere by heavy metals due to industrial, farming and domestic activities has now created serious problems for safe rational utilization of soils in agriculture. The main sources of trace elements to plants are their growth media (e.g. soil, air, nutrient solutions) from which trace elements are taken up by the root of the foliage. Certain trace elements are essential in plant nutrition (micronutrients), but plants growing in a polluted environment can accumulate metals at high concentrations, causing a serious risk to human health when plant-based food stuffs are consumed [Wenzel and Jackwer 1999; Qian et al 1996].

Heavy metal uptake by plant grown in polluted soils (mostly from anthropogenic activities such as sewage sludge application) has been studied to a considerable extent [Gigliotti et al. 1996]. Elevated levels of heavy metals in soils may lead to uptake by plant but there is not generally found high relationship between the concentration in soils and plants, because it depends on many different factors such as soil metal bioavailability, plant growth and metal distribution to plant parts [Kuboi et al. 1986; Xian 1989]. Consequently, element mobility and plant availability are very important when assessing the effect of soil contamination on plant metal uptake and related phytotoxic effects. Interactions between metals occuring at the root surface and within the plant can affect uptake as well as translocation and toxicity [Mentch et al. 1994]. High concentrations of heavy metals in the soil disrupt physiologically important functions in plants, cause an imbalance of nutrients and have an adverse effect on the synthesis and functioning of many biologically important compounds such as enzymes, vitamins and hormones [Luo and Rimmer 1995]. The purpose of this study was to determine the distribution of heavy metals in contaminated agricultural soils and to examine the availability to several vegetable species.

MATERIALS AND METHODS

The city of Thessaloniki with more than 1,2 million ihnabitants is located in Northern Greece. The greater industrial area in northwest part of the city was selected as a case study, since it combines a number of sources that

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emit heavy metals and other toxic elements (oil refinery, steel industry, fertiliser plant, ferrous and non-ferrous metal smelters, scrap metal incineration, manganese ore treatment and some hundreds of smaller industrial units). A major vegetable producing area of N. Greece is located near the industrial area (few km away from the emission sources and heavy traffic). Another area located in the southeast part of the city was also selected (Vasilika), which is a typical rural location of Chalkidiki and a vegetable producing area and characterized primarily by agricultural activities. This area is considered as unpolluted and was selected in order to make comparisons between the two areas and to determine the possible contamination of the soil and vegetation near the industrial area, arising from poor air waste management practices.

Samples of vegetables (spinach, leek, cabbage, lettuce, onion, cauliflower, celery, beetroot, carrot and envide) were collected from three sampling sites of the industrial area (Sindos, Ionia and Kalochori) and from one sampling site in Vasilika (as unpolluted reference site) during autumn 1999. From the samples composite samples were prepared. Surface soil samples (0-10 cm) were also collected from the same locations simultaneously with the vegetables. After delivery to the laboratory, samples were stored at 4°C and processed further as soon as possible. Vegetables were washed and non-edible parts were removed according to common household practices. Then, they were cut into small pieces, oven-dried at 60°C for 48 hours to constant weight. The dried products were homogenized by grinding in a stainless steel blender to pass through a 2 mm sieve. Soil samples were air dried, crushed, homogenized and grinded to pass through a 2-mm nylon sieve [Oyedele et al. 1995]. All samples were stored at ambient temperature until analysis.

A 1,000 g subsample of soil was digested in an open system with a mixture of concentrated HNO_3/$HClO_4$ at 150°C, while plant samples were digested with concentrated HNO_3. Fe, Mn, Ni, Cu, Zn in soil and plant extracts were determined by flame-atomic absorption spectroscopy (FAAS) and Pb and Cd by electrothermal atomic absorption spectroscopy (ETAAS) according to standard analytical procedures [APHA, AWWA, WPCF 1996]. A Perkin-Elmer 2380 AA spectrometer and an HGA-400 Programmer were employed for this purpose. The precision of the metal analysis was controlled by including triplicate samples in analytical batches, blanks and the method of standard additions. The relative standard deviations of means of triplicate measurements were less than 5%, which was regarded as a satisfactory precision. The results are expressed as a dry weight basis.

RESULTS AND DISCUSSION

The mean concentrations of the heavy metals Pb, Cd, Ni, Cu, Mn and Zn for all 60 samples of vegetables and soils have been presented in Figures

1 and 2 for both areas, industrial and rural. In the rural area no consistent differences are seen between the heavy metal content of leafy vegetables grown in the open and those from greenhouses. The largest differences in metal concentrations in vegetables between industrial and rural areas are found for lead in edvine, for cadmium in spinach, and for copper in celery and carrot. In addition, lead and zinc showed the largest differences between industrial and rural soils.

Table 1 shows the vegetable/soil concentration factor (CF) obtained from the ratio of each heavy metal concentration in vegetable to that in soil.

The highest CF value was observed for Cd in lettuce and the lowest for Cu in cabbage (Table 1). The CF values estimated were in good agreement with those reported by other investigations [Voutsa et al. 1997; Harrison and Chirgawi 1989]. The observed variations in CF values can be dued to a number of factors, such as the metal concentrations in soil, their chemical forms, variation in uptake capability between different plant species and growth rate of vegetation.

Table 1. Concentration factors (CF) for heavy metals for the industrial area

Metal	CF									
	spinach	leek	cabbage	lettuce	onion	caulifl	celery	beetrout	carrot	endive
Pb	0.46	0.19	0.19	0.32	0.21	0.26	0.30	0.30	0.07	0.33
Cd	1.67	1.22	0.81	1.75	0.27	0.44	1.35	0.78	1.24	1.15
Ni	0.07	0.07	0.08	0.03	0.16	0.15	0.16	0.06	0.07	0.10
Cu	0.37	0.08	0.01	0.24	0.31	0.01	0.24	0.30	0.18	0.26
Mn	0.22	0.08	0.12	0.17	0.14	0.18	0.21	0.22	0.04	0.20
Zn	0.36	0.27	0.20	0.30	0.35	0.37	0.38	0.33	0.17	0.29
Fe	0.14	0.05	0.05	0.11	0.10	0.04	0.10	0.09	0.05	0.14

Highest lead concentrations were observed for spinach in both areas (industrial and rural) and low values for carrot and leek respectively. The lead contents in vegetables and soils from the industrial area were higher than in the rural area and higher than those observed in previous studies [Voutsa et al 1997; Panagiotopoulos et al. 1976] because of the increased air pollution and traffic at this area. The higher lead levels are possibly due to the circumstance that contamination with lead mainly takes place via transport through air of lead containing dust particles. The concentration factor for lead ranged from 0.07 to 0.46.

All cadmium concentration factors found in our experiments are within the range 0.27 - 1.75. Spinach and lettuce grown on the soil of the industrial

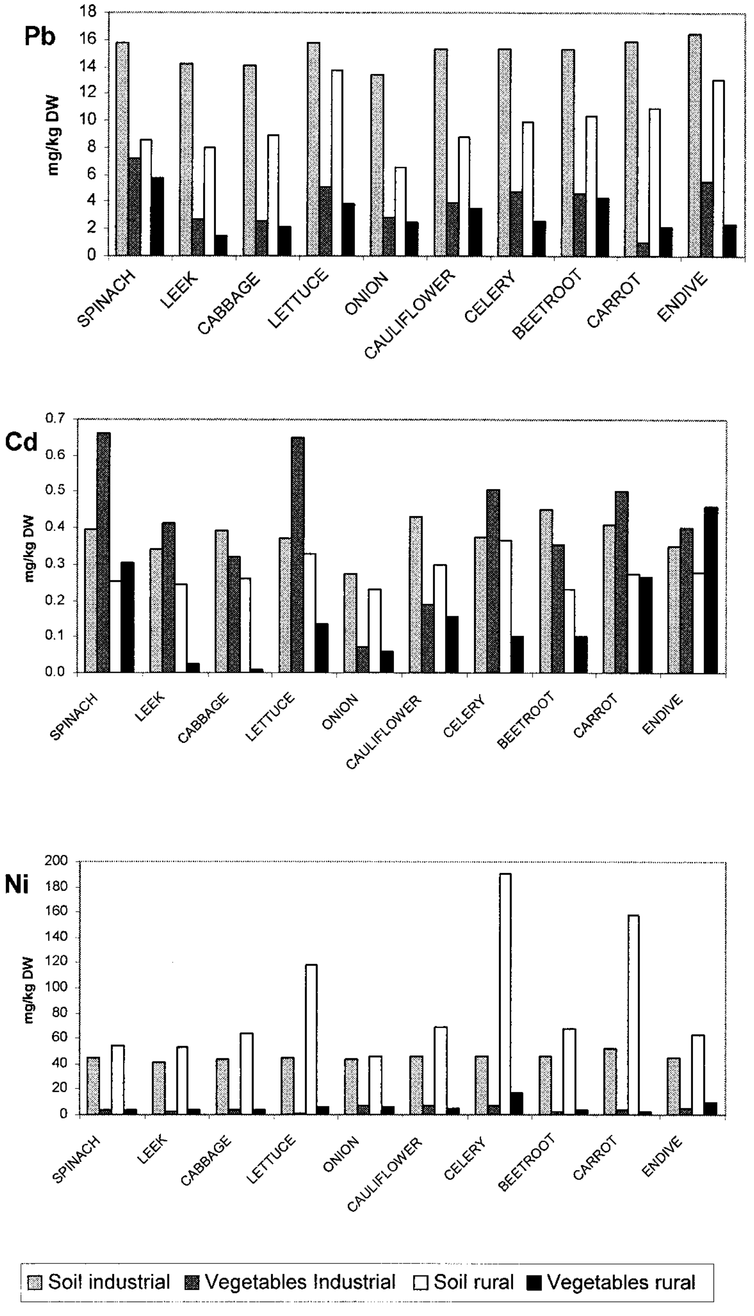

Figure 1. Mean concentrations of Pb, Cd, Ni for vegetable and soil samples from industrial and rural area

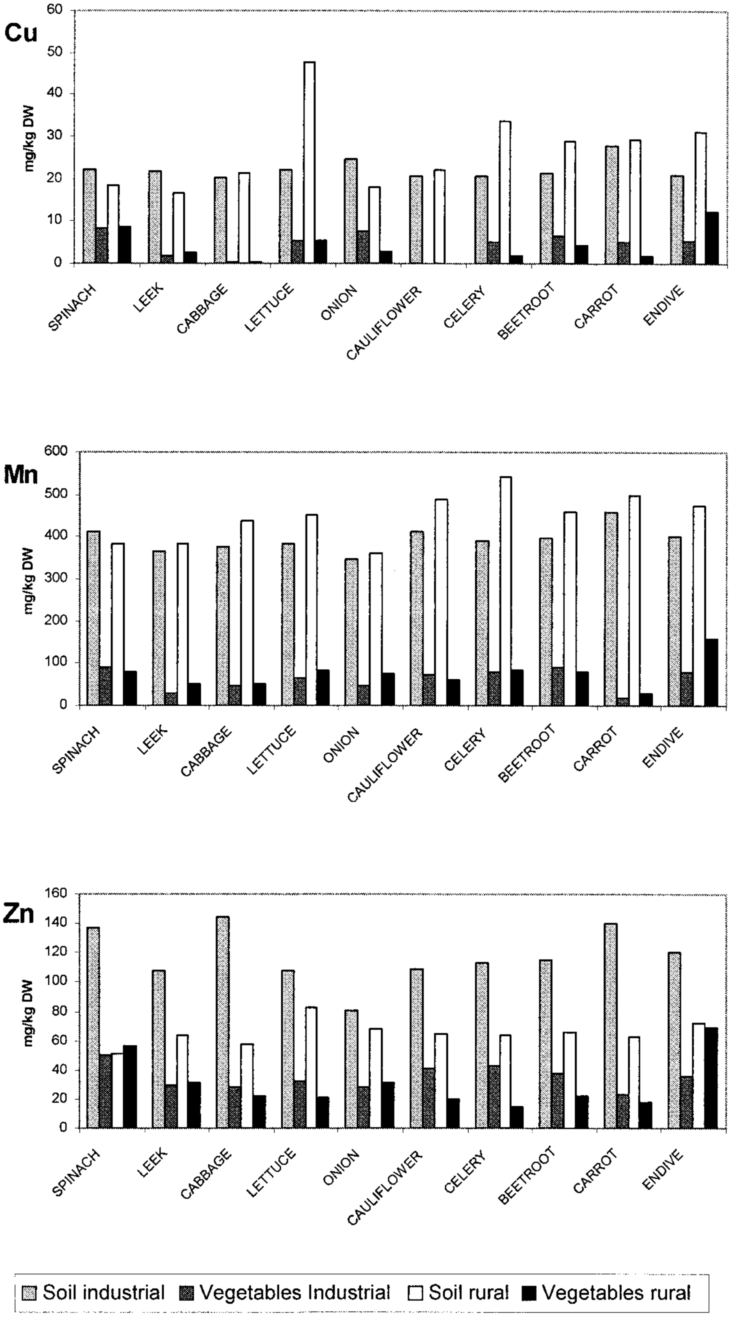

Figure 2. Mean concentrations of Cu, Mn, Zn for vegetable and soil samples from industrial and rural area

area are enriched in Cd. Spinach is already known for its high uptake of Cd. Root and leafy vegetables were found to accumulate Cd from soil much more efficiently than other heavy metals. The Cd contents in all vegetables of the industrial area are higher than in the equivalent plants in the rural area except from envide. Generally, the Cd concentrations in the plants ranged below 1 mg/kg and can be considered as "normal". Low contents and the slightly alkaline pH (6.5-7.8) in the soil reduce the mobility and the uptake of Cd.

Zinc contents on all soils and vegetables are in the normal range. The CF for Zn ranged from 0.17 to 0.38 (celery). The Zn concentrations determined in vegetables grown in the industrial area ranged from 23.2 to 47.9 mg/kg and in the rural area from 18.1 to 69.4 mg/kg. The lowest Zn content was found in carrot and the highest in spinach and endive. Zn content in cabbage and onion showed a similar pattern for the two areas.

Copper is an essential nutrient for plants, but concentrations of only 25 to 30 mg/kg (dry plant material) are already toxic and result in an inhibition of growth. Copper contents in the vegetables in both areas are below 10 mg/kg and can be classified as "normal". The CF showed the highest value for spinach and apart from the relatively high value for spinach no significant differences occured in the concentrations for all types of vegetables.

Manganese and iron apear to concentrate in spinach, endive, lettuce and onion. Iron concentrations in the soil appear in similar amounts for the two areas and ranged from 3003 to 3377 mg/kg, but in vegetables the iron concentrations were higher for some species in the rural area (504 mg/kg in spinach) and for some other species were higher in the industrial area (460 mg/kg in endive). Spinach, as it is known, is a strong iron accumulator. Largest variations were observed between vegetables species rather than between the two locations. Nickel, iron and manganese showed the lowest CF values in comparison to their other examined heavy metals, because these elements are found in very high concentrations in soils.

Vegetable and soil data obtained in this study were statistically analysed by two way analysis of variance (ANOVA) to examine whether factors such as sampling site or vegetable species have a significant effect on the observed variance. The high variation of metal concentrations limits the significancy of direct comparison of the two regions. The correlation of metal concentrations between soil and vegetables was poor for the majority of cases ($r < 0,75$). However, comparing the two regions, Pb concentrations in soil and vegetables are higher in the industrial area except in carrot. For Cd, the concentrations are higher in the soil also in the industrial area, but for the vegetables, higher values were obtained in the rural area except in endive. Concerning the Nickel concentrations in the soil of the rural area these are considerably higher than in the industrial area, probably due to the geochemical background values. In vegetables, the Ni concentrations were higher for the rural area except in onion, cauliflower and carrot.

The concentration levels determined in the present study were comparable generally to those previously found in the vegetables from the same area were found at concentrations normaly observed in vegetables grown in uncontamined areas [Geert et al 1990; Camazamo et al 1994; Dudka et al. 1996]. Heavy metal concentrations for the examined vegetables showed large variations even at the same location in the field. This is probably due to the different plant uptake. Generally most heavy metals were found at concentrations normally observed in vegetables grown in uncontaminated or slightly contaminated areas [Alloway 1990; Ward and Savage 1994].

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