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# The Use of Bioindication Plants for the Assessment of Air Pollutants in the City of Cochabamba, Bolivia

By

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Key words: Bioindication, accumulating plant, *Melia azederach*, *Schinus molle*, air pollutants, fluoride, chloride, sulphur.

Summary

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Fluoride, chloride and sulphur content of leaves of Chinaberry (*Melia azederach* L.) and Peruvian peppertree (*Schinus molle* L.) were investigated at the end of the dry season in 2000 and 2001 in the city of Cochabamba, Bolivia, to document the air pollution situation in this area. The leaf content of these pollutants where always slightly higher in *M. azederach* as compared *to S. molle*. Differences between sampling years and between sites could be detected and especially for chloride a point source for emission could be identified. It was possible to detect sulphur and chloride as an essential component of dust particles. Among gaseous pollutants dust has also be taken into consideration as a source of fluoride, chloride and sulphur. The presented study has proved the suitability of *M. azederach* and *S. molle* as bioaccumulators and further investigations should lead to the development of appropriate threshold levels for this region.

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## Introduction

In developing countries there is a significant increase of the urbanization process. Decades of unrestrained industrialization and urbanization have resulted in a dramatic deterioration of the environmental quality in many urban agglomerations and industrial areas of South American countries as well as in other regions of the Southern Hemisphere. During the last years, the rapid growth of the vehicular traffic has enhanced the environmental problems (KLUMPP & al. 2002a).

The city of Cochabamba, department of Cochabamba in central Bolivia, is also affected by the above mentioned problems. It is located in a basin at an altitude of 2600 m above sea level (a.s.l.) and is surrounded by the Andes with highest elevations up to 5000 m a.s.l.

During the dry season, May to September, rainfall occurs only occasionally and dust deposition becomes a severe problem. Investigations with passive dust sampling (Bergerhoff) and investigations of leaf surfaces of monitoring plants (Chinaberry, *Melia azederach* L.) revealed fine dust particles as being ubiquitous all over the city and being particularly high in places with a high traffic volume (ZABALLA ROMERO & al. 2004).

In general, the air pollution situation in Bolivian cities, and especially in Cochabamba, is not well documented. The presented study was performed to improve this situation.

In the city of Cochabamba a network using passive sampling systems was set up to measure the gaseous pollutants ozone ($O_3$), nitrogen oxides ($NO_x$) and sulphur dioxide ($SO_2$) (ZABALLA ROMERO 2004). In general, the measured concentrations of these pollutants were not alarming and below the corresponding European threshold values that were taken for comparison because of missing or not appropriate local thresholds. The distribution of the pollutants showed some characteristic local differences. Whereas the $NO_x$ concentrations were highest in the city centre and in areas with a high traffic volume the ozone concentrations were highest in the urban periphery, especially in the north and south of the city.

Besides the pollutant measurements representative monitoring plants were chosen to measure the dust deposition (ZABALLA ROMERO & al. 2004) and to investigate the leaf content of fluoride, chloride and sulphur.

The use of higher plants as accumulating indicators for air pollution has a long tradition. Bioaccumulators are plants that are in general less sensitive to air pollution but they accumulate airborne dust particles and gases onto and into their tissue (DE TEMMERMAN & al. 2004). Already in the 19$^{th}$ century and at the beginning of the 20$^{th}$ century plant organs were chemically analyzed to detect the impact of emitters (STEFAN & FÜRST 1998), and in some countries the use of bioindication techniques was even object of legal regulations (Austria; BGBL 1984) and Mexico City.

An accumulation of the pollutants in the plant is a requirement for their detection by chemical methods (WEISS & al. 2003). Therefore, reactive or rapidly metabolized compounds are not suitable for accumulative biomonitoring. Among them are pollutants of major environmental concern, like ozone, for which only effect related bioindication techniques exist (KRUPA & al. 1993, KLUMPP & al. 2002b, STABENTHEINER & al. 2003, 2004).

However, particularly significant accumulation rates can be assumed for sulphur, chloride and fluoride (SCHÄTZLE & al. 1990, VIKE & HABJORG 1995, STEFAN & FÜRST 1998). Several field studies showed excellent correlations between the concentrations in higher plants and the atmospheric pollution with organic and inorganic compounds detected by air measurements (GUDERIAN 1977, HORNTVEDT 1995, INNES 1995, MANNINEN & HUTTUNEN 1995).

For accumulating biomonitors in Europe a large data base of existing standardized and well developed methods is available that allows the selection of the appropriate bioindicator and bioindication technique to answer a specific problem. However, for many countries of the Southern Hemisphere and especially for Bolivia this information is not yet available.

For the objective of the study to characterize the air pollution situation in the city of Cochabamba it was necessary to select appropriate bioindicator plants which are widespread in the area. Chinaberry (*Melia azederach* L.) and Peruvian peppertree (*Schinus molle* L.) meet these requirements.

The content of fluoride, chloride and sulphur in the leaves of both trees was investigated to characterize the pollution situation and to test the suitability of these trees as accumulating bioindicators.

## Material and Methods

Leaves of *Melia azederach* L. (*Meliaceae*) and *Schinus molle* L. (*Anacardiaceae*) were sampled on several sites in the city (Fig. 1) at the end of the dry period in 2000 and 2001. For details see Table 1.

Table 1. Description of the sample sites in Cochabamba (compare Fig. 1): number of the measuring point; name of the place; altitude (m.a.s.l. - meter above sea level); data available (x) or not available (nd); classification: 1 - city centre, 2 - residential areas in the vicinity of the city centre, 3 - main roads of the residential areas in the vicinity of the city centre, 4 - suburban residential areas, 5 - suburban main roads, 6 - rural areas or green areas.

| Site | Place | Altitude (m a.s.l.) | *Melia azederach* 2000 | *Melia azederach* 2001 | *Schinus molle* 2000 | *Schinus molle* 2001 | Classification |
|---|---|---|---|---|---|---|---|
| 1 | Sucre 818, among 16 de Julio y Oquendo | 2610 | x | x | nd | nd | 1 |
| 2 | Plaza Colon, on the 25 de Mayo Street | 2630 | x | x | nd | x | 1 |
| 3 | Aroma esq. Ayacucho (SAR) | 2620 | x | x | x | x | 1 |
| 4 | PROMIC, End of the Atahuallpa Av. | 2788 | x | x | x | x | 4 |
| 5a | Pasaje La Sirenas 45, Sauna Las Sirenas | 2630 | x | x | nd | nd | 5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5b | Centro Médico Pacata | 2620 | nd | nd | x | x | 4 |
| 6 | Av. Atahuallpa 2550 (SEMAPA) | 2720 | x | x | x | x | 4 |
| 7a | Calle Illapa 1533 | 2630 | x | nd | x | nd | 2 |
| 7b | Av. Eduardo Ocampo esq. J. de La Rosa | 2660 | nd | x | nd | x | 2 |
| 8 | V. Amistad | 2760 | nd | nd | nd | | 6 |
| 9 | Av. Blanco Galindo km 4,5 (UNITEPC) | 2600 | x | x | nd | x | 5 |
| 10 | Ctro. Medico Quirúrgico San Alfonso | 2640 | nd | x | nd | x | 6 |
| 11 | Universidad Privada Boliviana (UPB) | 2605 | nd | x | nd | x | 6 |
| 12 | | 2660 | nd | x | nd | x | 6 |
| 13 | End of Av. Tadeo Haenke 42 | 2620 | x | x | nd | x | 4 |
| 14 | Street without name | 2625 | nd | nd | nd | nd | 6 |
| 15 | Av. Sofía Rossell | 2680 | x | x | x | x | 2 |
| 16a | Calle Martín Cárdenas 137 | 2600 | x | nd | nd | nd | 3 |
| 16b | C. Lope de Mendieta | 2610 | nd | x | nd | x | 2 |
| 17 | A one block of the Av. Petrolera km 4,5 | 2610 | x | x | x | x | 4 |
| 18 | Av. Petrolera /Refinería de Valle Hermoso | 2610 | nd | x | nd | x | 4 |
| 19 | Cerro Blanco. Street without name | 2610 | x | x | x | x | 5 |
| 20 | El Cristo de la Concordia | 2847 | x | x | x | x | 6 |
| 21 | Street without name | 2600 | nd | x | nd | x | 6 |
| 22 | C. Aurelio Meleán 0716 | 2620 | x | x | nd | x | 2 |
| 23 | Calle Acre 1627 | 2600 | x | x | nd | x | 2 |
| 24 | Calle Guadalquivir 0891 | 2610 | x | x | nd | nd | 2 |
| 25 | Av. Colquiri 111 | 2730 | x | x | nd | x | 4 |
| 26 | Calle Martín de La Rocha 01376 | 2605 | x | x | nd | nd | 3 |
| 27 | Av. Ramón Rivero 6072 | 2630 | x | x | nd | x | 1 |
| 28 | Parque Fidel Anze esq. Eudoro Galindo | 2660 | x | x | x | x | 2 |
| 29 | Calle Guzmán Rojas esq. Julio Garret | 2600 | nd | x | nd | x | 4 |

The sampled leaves were oven-dried at 80°C without prior washing, grinded with a mill and the powder was stored in paper bags until analysis.

For analysis of sulphur, chloride and fluoride the leaf powder was completely combusted in oxygen containing flasks (Schöninger combustion; RABER & al. 1976, TRUMMER 2000). Then the extracts were analyzed using ion chromatography (HPLC-system: Hewlett Packard Series 1100; column: Metrosep Anion Dual 2 IC anion column (Metrohm); detector: conductivity detector 732 IC with chemical suppression (Metrohm); suppressor: 833 advanced IC liquid handling suppressor unit (Metrohm); eluent: 2 mM Na-hydrogen carbonate, 1.8 mM Na-carbonate, 15 % (v/v) acetone).

The average values of the sites were used to generate isolines using the software SURFER, Version 8.0, Golden Software Inc. 2002.

For x-ray microanalysis of dust particles on the leaf surface air dried leaves of *M. azederach* were coated with carbon, investigated with a scanning electron microscope Philips XL 30 ESEM in the high vacuum mode using 20 kV acceleration voltage and x-rays were detected with an EDX-detector.

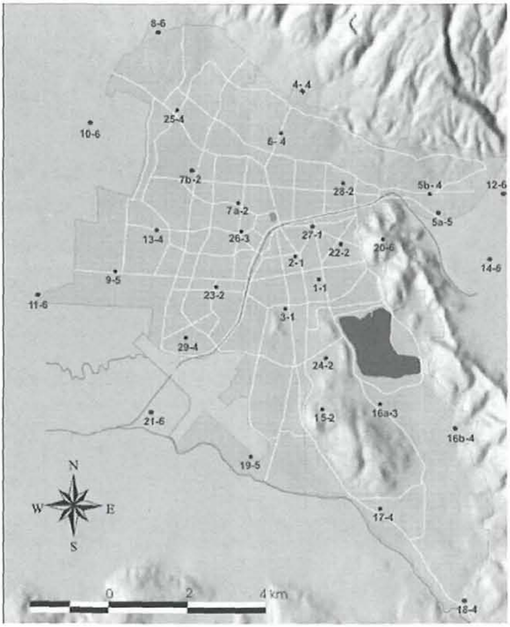


Fig. 1. Map of Cochabamba indicating the position of the measuring sites given in Table 1.

## Results and Discussion

The fluoride, chloride and sulphur content of the leaves of *M. azederach* and *S. molle* sampled at the end of the dry seasons 2000 and 2001 was investigated.

The ubiquitous element fluorine is a compound of more than 80 minerals, e.g. mica-schist, fluorite and apatite. Main natural fluoride sources are drifts of terrestrial dusts and marine aerosols. Anthropogenic sources are brickworks, glassworks, fertilizer production and incinerating plants and incinerators for fossil fuel (HALBWACHS & al. 2001).

Isolines of fluoride in the leaves of *M. azederach* for 2000 and 2001 are shown in Fig. 2. The fluoride concentrations were higher in the year 2000 and decreased from the west to the east of the city. In 2001 the fluoride concentrations were lower and more homogenous and no clear gradient could be detected. Information about the range of fluoride in the leaves of *M. azederach* and *S. molle* for polluted and unpolluted regions are not available. A reference value for a temporary evaluation can be found in Austria, were threshold limits for the fluoride concentrations in beech leaves were defined (B-GBl. 1984). This Austrian threshold limit for beech leaves (0.008 mg $g^{-1}$ dry weight) was distinctly exceeded on all sites.

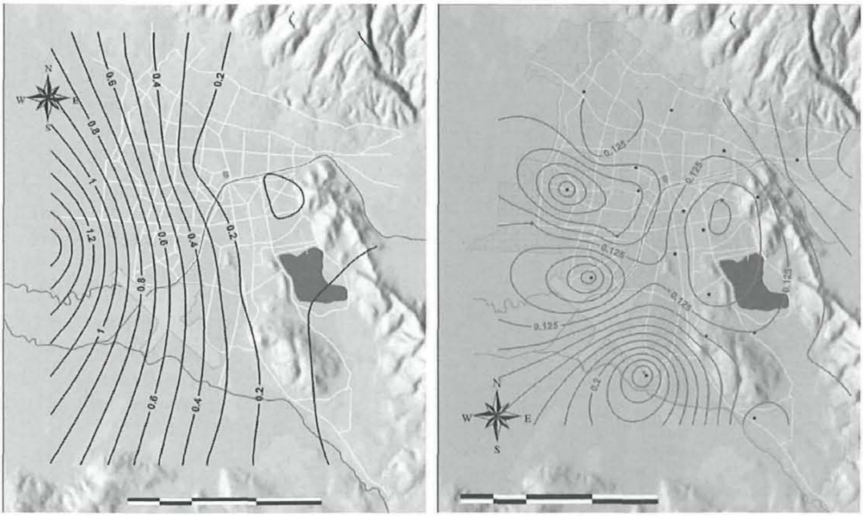


Fig. 2. Isolines of fluoride concentrations (mg $g^{-1}$ d.w.) in the leaves of *M. azederach* for 2000 (left) and 2001 (right).

Chloride is essential for higher plants. It is ubiquitous in nature, its mobility in the soil is high, concentrations in the soil solution vary over a wide range and it is readily taken up by plants (MARSCHNER 1995). Anthropogenic sources of chloride emissions are mainly production, application and combustion of chloride containing compounds, e.g. chlorinated hydrocarbons (MCLACHLAN & KRAUSE 2001). Airborne chloride can reach plant surfaces through wet and occult deposition, dry gaseous and dry particulate matter deposition and significant accumulation in plant parts has been detected (WEISS & al. 2003).

Chloride was detected in samples from both tree species. Differences were observed between *M. azedarach* and *S. molle* on the one hand and between sampling years and sites on the other hand (Fig. 3). Chloride concentrations in samples

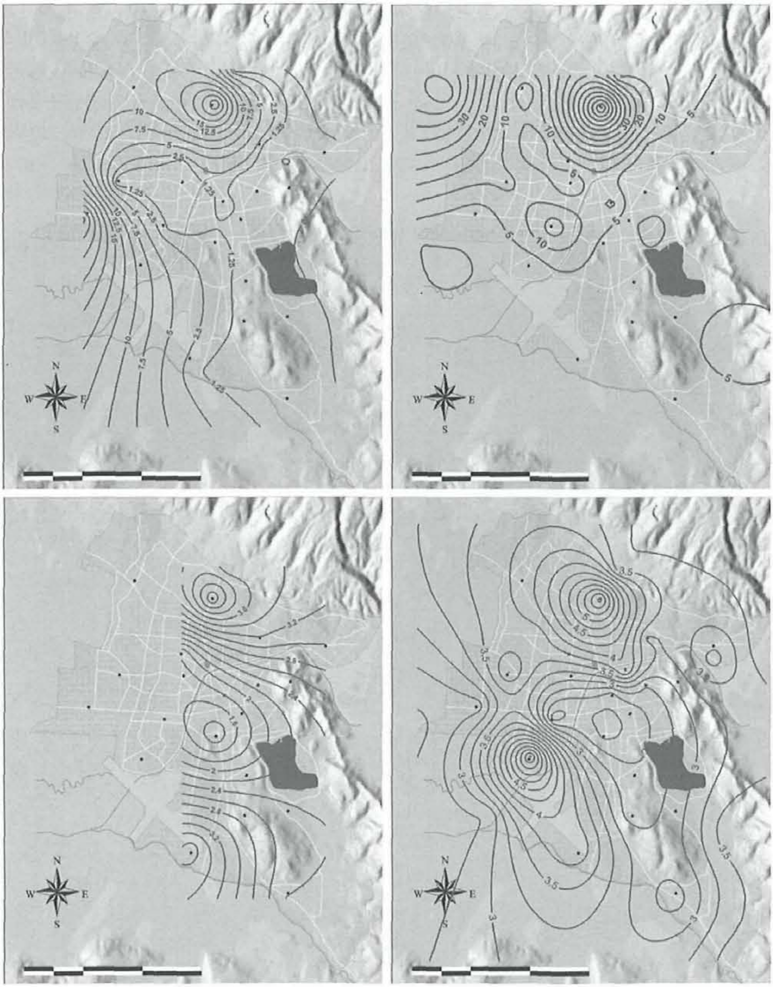

Fig. 3. Isolines of chloride concentrations (mg $g^{-1}$ d.w.) in the leaves of *M. azederach* (upper line) and *S. molle* (lower line) for 2000 (left) and 2001 (right).

from *M. azederach* were slightly higher as compared to *S. molle*. Chloride concentrations were higher 2001 as compared to 2000 for both tree species. And both bioindicators correspondingly showed the highest concentrations at a site north of the city centre (site 9; compare to Fig. 1). This site is in the vicinity of a water treatment plant where chloride is used in the water processing. Other sites with higher chloride concentrations were only slightly correlating between both tree species and were assumed to indicate local point sources of chloride emissions.

Local thresholds and chloride accumulation rates for both tree species are missing. However, compared to the threshold limit for chloride concentration in beech leaves defined in the Austrian law (BGBl. 1984; 1 mg $g^{-1}$ dry weight) the values are high and this threshold limit is exceeded on nearly all sites. Further investigations will be necessary to establish and test appropriate threshold limits for this region.

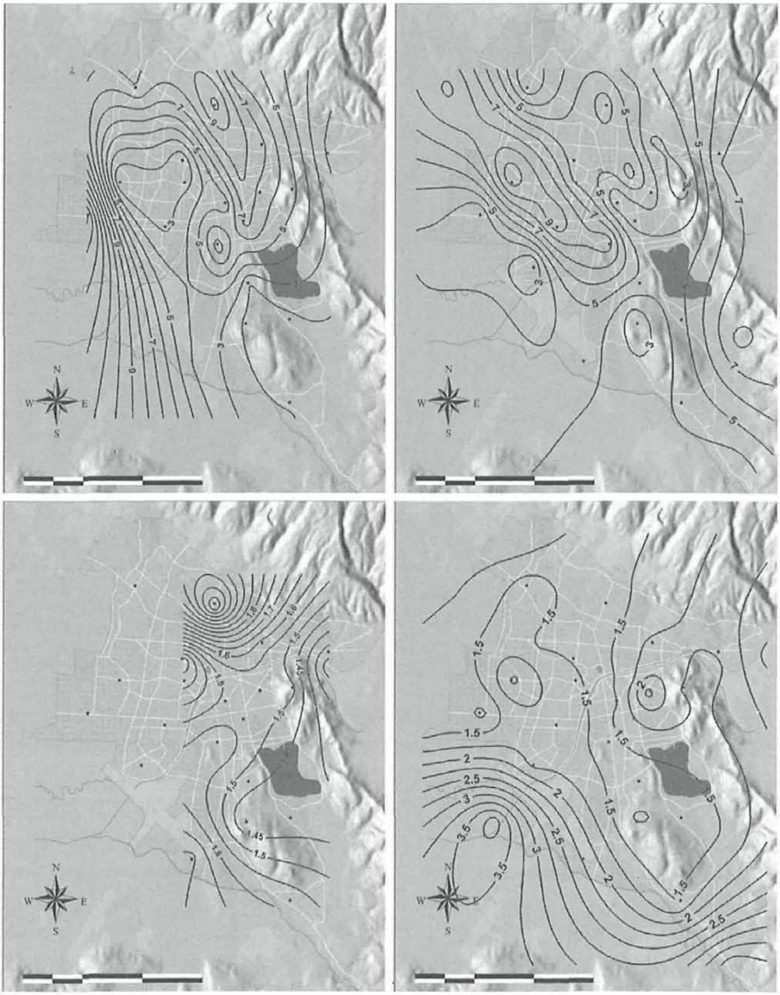

Fig. 4. Isolines of sulphur concentrations (mg $g^{-1}$ d.w.) in the leaves of *M. azederach* (upper line) and *S. molle* (lower line) for 2000 (left) and 2001 (right).

Sulphur impact can easily be identified by using bioaccumulators (GUDERIAN 1977, MANNINEN & HUTTUNEN 1995, STEFAN & FÜRST 1998, FÜRST & al. 2003, WEISS & al. 2003). The main anthropogenic sulphur source is sulphur dioxide emitted from combustion of fossil fuels (petrol, fuel oil, coal). In Austria intensive air pollution research resulted in a comprehensive database and as a consequence legal standards for the sulphur content of needles and leaves were established (FÜRST & al. 2003).

Comparable to chloride sulphur could be detected in all investigated samples with characteristic differences between the two plant species and differences in the spatial distribution pattern (Fig. 4). Again, the sulphur content of leaf samples from *M. azederach* was slightly higher as compared to *S. molle*. No distinct differences in total sulphur concentrations between 2000 and 2001 could be observed. Intersite differences in sulphur concentrations were much smaller as compared to chloride and no distinct "hot spots" could be identified.

As compared to legal standards from Austria (0.8 mg $g^{-1}$ dry weight) the sulphur concentrations in the leaves of both tree species are quite high. However, $SO_2$ emissions in the city measured with passive sampling methods were not alarming and below the corresponding European threshold values (ZABALLA ROMERO 2004).

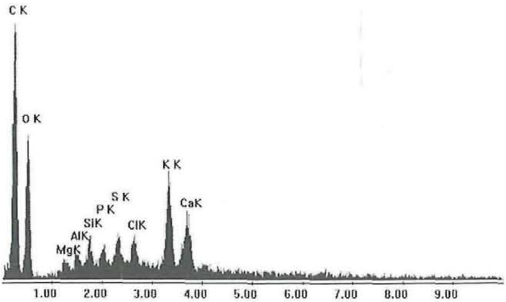


Fig. 5. X-ray microanalysis of a dust particle on the surface of *M. azederach*; x-axis - energy of X-rays (kV), y-axis - number of counts; symbol of the element is followed by the symbol for the electron shell (K).

Among gaseous pollutants dust has also be taken into consideration as a source of fluoride, chloride and sulphur. In Cochabamba, dust deposition was identified as a serious problem in the city especially in the dry season. Highest dust deposition rates were observed in the western part of the city area and soil could be identified as the main source of dust particles (ZABALLA ROMERO & al. 2004). Several studies gave evidence that leave surfaces work as accumulators of particle bound air pollutants (TRIMBACHER & WEISS 1999, WEISS & al. 2003). X-ray microanalysis of dust particles on the surface of *M. azederach* showed the presence of chloride and sulphur in such particles (Fig. 5). Fluoride can not be detected with this method. However, depending on the emission type up to 50% of the fluoride content of herbaceous leaves could be removed by a washing procedure (HALBWACHS & al. 2001). It is assumed that this percentage is even higher in Cochabamba where the emission situation is dominated by dust particles originating from the soil. The leaves were not washed prior to drying and analysis and to sum up it can be assumed that a significant amount of the measured fluoride, chloride and sulphur originated from dust on the leave surface.

The presented study has proved the suitability of *M. azederach* and *S. molle* as bioaccumulators in principle. However, fluoride, chloride and sulphur accumulation rates and sampling procedures (washing) have to be investigated in more detail. The aim of further studies should be the development of appropriate threshold levels for this region. Biomonitoring programmes that demonstrate accumulation and the negative effects of air pollution on plants revealed to be adequate means to give politicians and the public in general a better understanding of the need for more efficient air pollution control (KLUMPP & al. 2002b).

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