RELATIONSHIP BETWEEN HEAVY METAL CONCENTRATIONS IN SOILS OF TAIWAN AND UPTAKE BY CROPS

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ABSTRACT

In Taiwan, the sources of contaminants in rural and urban soils are mainly wastewater containing heavy metals, organic wastes and corrosive metal wastes. About 800 ha of rural soils are highly contaminated with heavy metals, and so are some urban soils. A process of establishing reference background levels and monitoring level of contamination by heavy metals has been established. Some studies have indicated a relationship between the concentration of trace elements in soils and that in crops in different parts of Japan and Taiwan. These serve as the basis for determining critical values of trace elements, especially of cadmium, in soil, corresponding to the allowable maximum level in contaminated food. Remediation techniques have been carried out in some contaminated rural sites, and these are described. Exchangeable (or available) forms of cadmium and lead can be transformed into unavailable forms by applying amendments of manganese oxide, calcium carbonate or zeolite to the soil.

INTRODUCTION

Taiwan is a densely populated and highly industrialized island. It has a subtropical climate, with an annual rainfall of more than 2500 mm/year, while the average temperature is around 22°C. This Bulletin describes the production of wastes in Taiwan, mainly as a by-product of industrial processing, and how the government is dealing with these. It discusses the relationship between the presence of heavy metals in the soil, and their uptake by crops. Finally, it describes current programs to regulate maximum permissible levels of trace elements in the soil, and remedial treatments for contaminated soils.

THE PRODUCTION OF INDUSTRIAL WASTES IN TAIWAN

There are more than 100,000 registered industrial plants in Taiwan, about one-fifth of which produce wastewater. The government has obtained detailed information about waste disposal from about 18,000 of these factories. Most are located in one of the 88 industrial parks administered by the government. Only about 50% of industrial parks offer a centralized system of wastewater collection and treatment. There are 30 wastewater treatment plants in industrial parks, which together treat 110,000 m³ wastewater from 2,103 factories, while some 2,037 factories are responsible for treating their own wastewater (158,000 m³). There are also factories outside the industrial parks. With regard to solid industrial wastes, most are general wastes but some are hazardous wastes. The method of distinguishing haz-
ardous wastes from general industrial wastes follows that of USEPA. It is estimated that 30 million mt of industrial wastes are generated in Taiwan each year. Those classified as hazardous wastes make up about 3 million tons (10% of the total).

**Effect of Pollution from Wastewater and Solid Wastes**

From the information already published, it is clear that Taiwan’s facilities for the treatment of urban sewage and municipal and industrial solid wastes are very limited. Most wastes are not treated at all, causing severe contamination of soil and water. More than 40% of the rivers in Taiwan are moderately to heavily polluted and have no beneficial use (EPA/ROC 1998).

Many agricultural fields located near industrial complexes are polluted by industrial wastewater. A notorious case was that of two chemical factories in Taoyuan county, about 50 kilometers from Taipei. The two factories had been continuously discharging untreated wastewater containing cadmium (Cd) and lead (Pb) into nearby agricultural fields for several years. As a result, about 100 ha of arable land had become unusable. A high level of cadmium had accumulated in rice grain (mean value 2.5 mg/kg), in concentrations harmful to human health (Chen 1992, Chen et al. 1994).

The discharge of untreated domestic sewage, pig manure and industrial wastewater also contaminates irrigation water in many parts of Taiwan. This indirectly causes the accumulation of nitrate salts, and heavy metals such as copper (Cu) and zinc (Zn) in agricultural soils.

**Sources of Soil Contamination**

Rural and urban soils in both industrial parks and near small factories outside the parks are affected by a wide variety of contaminants. The most serious sources of soil contamination are (EPA/ROC 1994):

- Heavy metals in hazardous waste, including materials from chemical production, dyeing, electroplating and heat treatment, the production of batteries, metal treatment, mining and extractive industries, scrap yards, service stations and tanning;
- Hazardous organic waste materials, including those from medical centers, oil production and storage, and paint and pesticide production; and
- Corrosive metal waste materials, including those from acid/alkali plants and chemical engineering works.

**BACKGROUND LEVELS OF TRACE ELEMENTS IN THE SOILS AND CROPS OF TAIWAN**

**Trace Elements in the Soil**

A survey of heavy metal contamination in rural soils has been carried out since 1982 (EPA/ROC 1989). The results are shown in Table 1 and Table 2. According to this survey, 787 ha of rural soils were regarded as highly contaminated (EPA/ROC 1989). The bioavailable concentrations of heavy metals extracted by 0.1 M HCl in these soils were higher than the critical levels proposed by the government, which were (per kg dry soil): 100 mg/kg for copper, 10 mg/kg for cadmium, 16 mg/kg for chromium, 100 kg/mg for nickel, 120 kg/mg for lead, and 80 mg/kg for zinc. The major trace elements found in these contaminated soils were cadmium, copper, chromium, nickel, lead and zinc.

**Trace Elements in Food Crops**

Lin (1991) conducted a detailed survey of the levels of eight elements (arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc) in vegetables and other food crops in Taiwan. As well as brown rice (n = 341), the crops surveyed included fruit type vegetables (n = 90), leaf type vegetables (n = 144) and root type vegetables (n = 112). The mean values and range of concentration of the eight elements are shown in Table 3. The mean value of the eight heavy metals in brown rice in Taiwan are (mg/kg air-dried soil): Arsenic 0.17, Cadmium 0.07, Chromium 0.16, copper 2.48, Mercury 0.001, Nickel 0.54, Lead 0.43, and Zinc 39.2 (Lin 1991).

**CONTAMINATED SOILS AND CROPS IN TAIWAN**

**Contamination of Rural Soils**

Five seriously contaminated sites in rural areas have been identified. The contaminated soils contained cadmium, lead and other elements, and covered around 100 ha. The sites were contaminated by wastewater with a high lead and cadmium content, discharged from chemical engineering plants which produce plastic stabilizing materials.
Levels of cadmium in two of the sites were very high, ranging from 175 - 378 mg/kg, while levels of lead were as high as 252 - 3145 mg/kg (Table 4).

Contamination of Urban Sites

The total heavy metal content in soils in commercial and residential districts of Taiwan has been investigated. High concentrations of lead and zinc (> 100 mg/kg) were found in some urban soils, especially in the capital city of Taipei and three other large cities. One of these cities, Kaoshiung, is highly industrialized, with iron and steel foundries, oil refineries, and chemical engineering plants. Urban soils in Taiwan are also contaminated by heavy metals, especially cadmium, chromium, copper, nickel, lead and zinc. The maximum concentrations of heavy metals extracted with 0.1 M HCl in soils from two cities in central Taiwan are listed in Table 5. The sources of contamination were wastewater discharged from chemical and metal treatment plants.

Heavy Metal Content of Compost

More than eight million mt (dry weight) of hog and chicken manure are produced every year in Taiwan. If this manure could be composted and

| Table 1. Background total concentration of heavy metals in rural soils in Taiwan |
|---------------------------------|-----------------|-----------------|
| **Element**         | **Total Concentration (n = 100)** | **Upper limit** |
|                    | Range | Mean | Std** | mg/kg | mg/kg |
| Arsenic            | ND-10.8 | 4.54 | 3.28 | 10 |
| Cadmium            | 1.02-3.41 | 1.74 | 0.62 | 3 |
| Chromium           | 22.9 - 98.9 | 43.2 | 15.1 | 100 |
| Copper             | 7.15-35.1 | 20.3 | 7.63 | 35 |
| Mercury #          | ND-0.47 | 0.13 | 0.10 | 0.49 |
| Nickel             | 18.6-66.7 | 43.2 | 12.6 | 60 |
| Lead               | 7.50-138 | 32.6 | 28.2 | 120 |
| Zinc               | 30.1-392 | 180 | 80.5 | 120 |

+ : Chen and Lee (1995)
++ : A value: Upper limit of background total concentration of heavy metals in Taiwan (Chen et al. 1992c)
# : 1473 soil samples (Chen et al. 1992c)

| Table 2. Background concentration of heavy metals extracted with 0.1 M HCl (approximating the levels available to plants) in surface soils (0-15 cm depth) in rural Taiwan |
|---------------------------------|-----------------|-----------------|
| **Elements** | **0.1 M HCl extractable (n=1473)** | **Upper limit** |
|                | Range | Mean | Std** | mg/kg | mg/kg |
| Cadmium         | ND-0.38 | 0.09 | 0.10 | 0.43 |
| Chromium        | ND-7.51 | 0.75 | 1.43 | 12.0 |
| Copper          | ND-17.8 | 5.96 | 4.03 | 26.0 |
| Nickel          | ND-8.87 | 2.36 | 1.68 | 12.0 |
| Lead            | ND-21.4 | 9.01 | 4.54 | 18.0 |
| Zinc            | ND-34.3 | 9.90 | 5.85 | 25.0 |

# : Chen et al. (1992c)
+ : Maximum level in samples tested
++ STD : Standard deviation

(Chen 1991). Levels of cadmium in two of the sites were very high, ranging from 175 - 378 mg/kg, while levels of lead were as high as 252 - 3145 mg/kg (Table 4).
applied to agricultural soils, it would significantly increase the levels of soil organic matter and soil fertility. The organic matter content of paddy soils in Taiwan ranges from 1 to 2% at a depth of 0 - 20 cm. High concentrations of copper, zinc, chromium and nickel were found in commercial composts made from hog and chicken manure. These levels were higher than the allowable concentration of heavy metals in commercial fertilizers sold in Taiwan (Chen and Lee 1997b). The maximum permitted levels are as follows:

- In commercial compost made from municipal refuse, maximum levels (mg/kg dry weight) are: Cadmium 5, nickel 25, arsenic 50, lead 150, chromium 150, copper 150, and zinc 150.
- In commercial compost made from hog and chicken manure, maximum levels (mg/kg dry weight) are: Nickel 25, chromium 150, copper 100, and zinc 800 mg/kg.

The maximum loading capacity (MLC) of trace elements applied to soils can be calculated according to the difference between the background concentration, and the maximum permitted concentration in soils. The approximate value of the MLC of trace elements applied each year to surface soils can be calculated as (kg/ha): cadmium 370, chromium 370, copper 300, nickel 180, lead 140, and zinc 250 (Chen and Lee 1997b). On this basis, the maximum application of composted hog manure compost in Taiwan to agricultural soils is about 500 mt/ha, while the maximum level of composted chicken manure is around 250 tons/ha (Chen and Lee 1997b). If compost is applied at or below these levels, soil quality can be maintained and the soil should not be polluted by accumulated trace elements.

Contamination of Crops

The highest concentration of cadmium found in brown rice grown in contaminated soils in Taiwan was 5.9 mg/kg dried rice, while the mean level was 2.5 mg/kg (Chen et al. 1994). The maximum permissible cadmium concentration in rice is only 0.5 mg/kg (DOH/ROC 1988).

RELATIONSHIP BETWEEN BIOAVAILABILITY OF TRACE ELEMENTS IN THE SOIL, AND UPTAKE BY CROPS

Concentration of Trace Elements in Soils and in Crops

Traditionally, trace elements in Taiwan soils are extracted by 0.1 M HCl to determine the bioavailability i.e. the quantity of trace elements which can be taken up by crops.

Three patterns of the relationship between the bioavailability of nutrients and uptake in the crops have been proposed (Fig. 1) (Wang and Liao 1999). In Type 1, uptake increases as the crop grows, then falls when the crop reaches maturity. This pattern is seen in the uptake of major nutrients such as nitrogen, potassium and phosphorus. Type 2 has a similar but steeper peak, and is seen with the uptake of micro nutrients such as copper or zinc. In Type 3, uptake is highest at the early growing stages.

<table>
<thead>
<tr>
<th>Element</th>
<th>Brown rice (n=341)</th>
<th>Fruit type vegetables (n=50)</th>
<th>Leaf type vegetables (n=144)</th>
<th>Root type vegetables (n=112)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/kg of vegetable (dry matter basis)</td>
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<tr>
<td>Arsenic</td>
<td>0.17</td>
<td>0.05</td>
<td>0.12</td>
<td>0.05</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.07</td>
<td>0.11</td>
<td>0.24</td>
<td>0.21</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.16</td>
<td>0.26</td>
<td>0.02</td>
<td>0.03</td>
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<tr>
<td>Copper</td>
<td>2.48</td>
<td>3.52</td>
<td>4.64</td>
<td>3.00</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.001</td>
<td>0.02</td>
<td>0.04</td>
<td>0.03</td>
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<tr>
<td>Nickel</td>
<td>0.54</td>
<td>0.95</td>
<td>2.14</td>
<td>1.63</td>
</tr>
<tr>
<td>Lead</td>
<td>0.43</td>
<td>2.11</td>
<td>3.69</td>
<td>2.58</td>
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<tr>
<td>Zinc</td>
<td>39.2</td>
<td>27.7</td>
<td>38.1</td>
<td>27.4</td>
</tr>
</tbody>
</table>

Source: Lin 1991
and falls during later stages of growth. This pattern is seen for heavy metals such as arsenic, cadmium, chromium, lead, nickel and mercury.

Cadmium is soluble in soil under oxidized conditions. Under reducing conditions, it is precipitated as cadmium sulfate. Rice contains more cadmium if it is planted in relatively dry soil, than if it is planted under flooded conditions. Since rice is normally planted in flooded soils, there is not a simple, direct relationship between cadmium concentrations in soil and harvested rice grown under flooded conditions.

However, high levels of cadmium in the soil may produce high levels in rice. Some studies have indicated a relationship of this kind in some parts of Japan and Taiwan (Morishita 1975, Li and Lin 1988, Chen 1991, Liu et al. 1998). Data from Japan has established the critical values of cadmium in soils, corresponding to 1.0 mg Cd/kg in unpolished rice (the maximum permitted level in Japan). The level of cadmium in the soil ranged from 0.5 to 1 mg Cd/kg soil (Li and Lin 1988, Chen 1991, Liu et al. 1998).

Scientists in Taiwan carried out a similar study to find the critical values of cadmium in the soil, extracted by 0.1 M HCl, corresponding to 0.5 mg Cd/kg of polished rice (the maximum permitted level in Taiwan). The level of cadmium in the soil ranged from 0.5 to 1 mg Cd/kg soil (Li and Lin 1988, Chen 1991, Liu et al. 1998).

There was a significant relationship between the levels of cadmium (or lead) in the roots or grain of rice, and the amount of cadmium (or lead) in the soil extracted by 0.05 M EDTA or 0.005 M HCl.

### Table 4. Levels of heavy metals in contaminated soils, rural Taiwan

<table>
<thead>
<tr>
<th>Site</th>
<th>Area (ha)</th>
<th>Element</th>
<th>0.1M HC1 extractable</th>
<th>Total concentration</th>
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<tbody>
<tr>
<td></td>
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<td>Range</td>
<td>Mean</td>
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<td></td>
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<td>mg/kg Dry soil</td>
<td>mg/kg Dry soil</td>
</tr>
<tr>
<td>A</td>
<td>17</td>
<td>Cadmium (n=20)</td>
<td>...+</td>
<td>45-1,319</td>
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<td></td>
<td></td>
<td></td>
<td>...</td>
<td>378</td>
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<tr>
<td></td>
<td></td>
<td>Lead</td>
<td>...</td>
<td>67-12,740</td>
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<td>...</td>
<td>3,145</td>
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<tr>
<td>B</td>
<td>22</td>
<td>Cadmium (n=37)</td>
<td>...</td>
<td>0.4-1,486</td>
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<td>...</td>
<td>175</td>
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<td></td>
<td></td>
<td>Lead</td>
<td>...</td>
<td>5.5-973</td>
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<td>...</td>
<td>252</td>
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<td>C</td>
<td>13</td>
<td>Cadmium (n=118)</td>
<td>1.12-148</td>
<td>16.4</td>
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<td>6.3-127</td>
<td>25.8</td>
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<td>Lead</td>
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<td>D</td>
<td>45</td>
<td>Cadmium (n=157)</td>
<td>ND-25.4</td>
<td>2.1</td>
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<td></td>
<td></td>
<td>2.1-56.6</td>
<td>13.1</td>
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<tr>
<td></td>
<td></td>
<td>Lead</td>
<td>...</td>
<td>...</td>
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<tr>
<td>E</td>
<td>3.6</td>
<td>Cadmium (n=20)</td>
<td>...</td>
<td>0.71-1.80</td>
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<td>...</td>
<td>1.38</td>
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<td></td>
<td>Copper</td>
<td>...</td>
<td>27.5-113</td>
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<td>...</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nickel</td>
<td>...</td>
<td>43-126</td>
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<td>...</td>
<td>111</td>
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<td>Lead</td>
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<td>24-40</td>
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<td></td>
<td></td>
<td>Zinc</td>
<td>...</td>
<td>111-214</td>
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<td>...</td>
<td>189</td>
</tr>
</tbody>
</table>

# Site A and B: Northern Taiwan, Lyu et al. (1984)
Site C: Northern Taiwan, Chen (1988)
Site D: Northern Taiwan, Li and Lin (1988)
Site E: Central Taiwan, Wang et al. (1994a)
+: ... No data.

Source: Chen et al. 1994
DTPA ($p < 0.01$) (Lee 1999). It seems that:

- Cadmium in the soils of northern Taiwan can be absorbed more easily by rice plants than in other parts of Taiwan. Cadmium uptake was influenced by soil properties, particularly clay content and pH.
- It is difficult to understand the relationship between the concentration of cadmium in brown rice and the concentration of cadmium in soil, especially when cadmium was extracted by 0.1 M HCl. It seems that this method is not suitable for predicting the uptake of cadmium by the rice plant.

MANAGEMENT FACTORS AFFECTING THE CONCENTRATION OF HEAVY METALS IN CONTAMINATED SOILS

Soil Remediation Techniques

Many field and pot experiments on remediation techniques for contaminated soils have been carried out in Taiwan (Lee and Chen 1994, Wang et al. 1994a, 1994b Chen and Lee 1997a). These include:

- Chemical stabilization, to reduce the solubility of heavy metals by adding nontoxic materials to the soil;
- Removal of polluted surface soil, and re-

![Fig. 1. The influence of essential and non-essential elements on the growth of the crop](source: Wang and Liao 1999)
placing it with clean soil;
- Covering the original polluted soil with clean soil;
- On-site chemical leaching, using some acid agent;
- The dilution method, mixing polluted soil with clean soil to dilute the concentration of heavy metals;
- Remediation by plants, using for example suitable tree species.

As discussed in the final section of this Bulletin, chemical stabilization seems to be the most cost-effective remediation technique for contaminated sites. However, methods involving the removal of polluted soil, and the addition of clean soil to the surface, or remediation by plants, were also effective in some cases (Chen et al. 1997).

### How Soil Chemical Amendments Affect Heavy Metals in Soils

Some chemical techniques are available which help immobilize heavy metals in soil, so that they cannot be taken up by plants. These include the application of dolomite, phosphates or organic matter into polluted soil. Such materials can reduce the concentration of heavy metals by precipitation, adsorption, or complexation (Impens et al. 1991, Mench et al. 1994, Chen and Lee 1997a). The application of calcium carbonate (limestone) materials significantly reduces the solubility of heavy metals in contaminated soils (Kuo et al. 1984, Chen et al. 1997, Liu et al. 1998). Many reports also indicate that the application of iron hydroxides or manganese oxides significantly reduces the concentration of soluble cadmium or lead in contaminated soil (McKenzie 1980, Tiller et al. 1984, Khattak and Page 1992, Mench et al. 1994, Chen et al. 1997). Soil pH is a crucial factor in the extractability of cadmium and lead in contaminated soils. In the studies carried out in Taiwan, soils amended with calcium carbonate so that the pH was around 7 had the lowest rate of cadmium extraction, compared to other soil amendments.

This means that plant uptake of cadmium would be low on such soils. There is also a significant decrease in the levels of extractable lead when the soils are amended with calcium carbonate, manganese oxide or zeolite (p < 0.10). These results coincide with other findings that the application of lime, iron hydroxides or manganese oxides can significantly reduce the solubility of lead in contaminated soils. The application of zeolite may also significantly reduce the solubility of lead in the soil. Without amendments, the concentration of extractable lead in heavily contaminated soils was very high, at more than 250 mg/kg dry soil.

### Management Factors Affecting the Form of Heavy Metals

Heavy metals may be present in one of a number of forms. Some of these are available to plants (e.g. the soluble form) while others (the organic, sulfide and residual forms) are not. Tests carried out on a contaminated soil in northern Taiwan indicated that the soluble form of cadmium was the most common chemical form, comprising 56-76%
of the total cadmium content.

In contaminated soil with a low lead content, the residual fraction of lead was the most common form. This is not available to plants. In soils with a higher lead content, however, the other three fractions (including the soluble form, the iron- and manganese-bound forms, and the organically bound and sulfide fraction) were almost equally important (20% to 30% of the total content for each form).

Chen et al. (1997) found that applying amendments of calcium carbonate or zeolite transformed exchangeable forms of cadmium and lead into unavailable forms (i.e. the organic, sulfide and residual fractions). This is a very effective way of reducing the cadmium and lead uptake by crops.

**Effect of Management on the Concentration of Trace Elements in the Soil Solution**

In pot experiments, Chen and Lee (1999) found that the application of calcium carbonate to contaminated soils significantly increased the soil pH, and promoted better growth and yields in wheat. However, wheat showed little response to applications of compost or zinc oxide. The concentration of cadmium in the soil solution fell significantly when calcium carbonate was applied to contaminated soil. The level of cadmium in the wheat grain also fell. However, amendments of zinc oxide or compost had no significant effect.

**REGULATIONS GOVERNING HEAVY METALS**

**Regulation of Heavy Metals in Soils in Developed Countries**

Various approaches are used in different countries to assess the level of heavy metals in contaminated soils. Regulations governing the maximum permitted levels in a number of developed countries are shown in Table 6. Most governments who have not developed their own formal guidelines follow the “Dutch Standard” to support their decisions in assessing and monitoring sites. Other governments have developed their own regulations, based on the soil qualities they require.

Dutch authorities are improving their soil quality criteria in the light of new scientific work, especially about the impact of listed substances on living species and ecosystems (Denneman and Robberse 1990). Two values are particularly important in making decisions on the regulation of heavy metals in soils. These are the target value (the A-value, the normal or natural level) and the intervention value (the C-value, the clean-up level) (Ministry of Housing, Netherlands 1994). Dutch standards for assessing soil contamination are shown in Table 7.

**Regulation of Heavy Metals in Soils in Taiwan**

A working group was organized by the government in 1991 to develop guidelines for monitoring sites, and to assess levels of heavy metal in polluted sites (Wang et al. 1994b, Chen et al. 1996). These guidelines are based mainly on soil properties, and the effect of heavy metals on:

- Water quality;
- The activity of soil microorganisms;
- Human health, and
- Crop yield and quality.

By 1994, this working group had formulated standard values to assess soil quality. These included A values (the upper limit of the background concentration), B values (the acceptable level), and C values (the intervention level, at which pollution control is needed). Levels of heavy metal were not the total soil content, but the level available to plants (i.e. extracted by 0.1 M HCl) (Wang et al. 1994b) (Table 8). A "Soil Remediation Act" was developed to enforce these standards. It is now being considered by the legislature, and it is hoped that it will come into force this year (2000).

**Permissible Levels of Heavy Metals in Crops**

Rice is Asia’s most important food. Most Asian governments have established critical maximum levels of heavy metals in rice to protect the health of their citizens. In Japan, the maximum level of cadmium in unpolished rice is 1.0 mg Cd/kg (Asami 1981). In Taiwan, it is 0.5 mg Cd/kg, while in mainland China the maximum permitted level is 0.4 mg Cd/kg polished rice (Yang and Kuboi 1989). Taiwan also has a maximum mercury level in harvested rice of 0.05 Hg/kg.
ASSESSMENT OF SITES WITH POTENTIAL HEAVY METAL CONTAMINATION

The process of assessing sites which are possibly contaminated with heavy metals can be divided into four stages (Chen et al. 1996).

First Stage

- Initial evaluation based on a survey of the site.
- Preliminary sampling and analysis of heavy metals at the site. In Taiwan, 20 soil samples are mixed into one representative soil sample for each 100 hectare or 25 hectare area.
- Preliminary assessment based on the levels of heavy metals found in these tests.

Second Stage

- Second stage of sampling and analysis, taking one soil sample per hectare, in areas where the concentration of heavy metals seems to be above the permitted limit.
- Assessment of public health risks, based on the total heavy metal content in soil and brown rice.
- An environmental impact assessment, emphasizing soil, crop, and water quality.

Third Stage

- Contaminated sites are publicly announced, and the options for site management are determined from the various clean-up methods proposed by scientists.

Fourth Stage

- Implementation of clean-up measures, with monitoring of changes in the concentration of heavy metals at the site.

EVALUATION OF MAIN SOIL REMEDIATION TECHNIQUES IN TAIWAN

Different soil remediation techniques, including engineering, chemical, and biological treatments, were tested at two sites in northern Taiwan where the soil was contaminated with cadmium and lead (Chen et al. 1992a and 1992b, Chen 1994a, Chen et al. 1994, Lee and Chen 1994, Wang et al. 1994a, Chen and Lee 1997b, Lo and Che 1997). Two technical committees were organized to supervise the soil remediation program. One committee focused on organic pollutants, and the other committee was concerned with heavy metals. These committees were a good way of linking local governments and local citizens with the government's Environmental Protection Agency, and communicating the concepts and techniques of soil remediation.

Engineering Remediation Techniques

The most effective engineering remediation technique is the removal of polluted surface soil, which is replaced by non-contaminated soil. After removal, the contaminated soil is washed with some chemical extraction or chelating reagent (Chen et al. 1994). This process is both effective and relatively low-cost.

Chemical Remediation Techniques

Chemical remediation techniques involve adding some chemical material to polluted soils, in order to reduce the concentration of cadmium and lead dissolved in the soil solution. These chemical materials include the following:

- **Lime materials, manure or compost**, to increase the soil pH and reduce the solubility of trace elements.
- **Iron hydroxides, manganese oxides or zeolite** to increase the adsorption sites of trace elements.
- **Heavy applications of phosphate** to increase the precipitation of metal ions and phosphate ions.

Some reports also indicate that the application of hydrous oxides of iron, manganese or zeolite can reduce the concentration of cadmium or lead dissolved in contaminated soil (McKenzie 1980, Tiller et al. 1984, Khattak and Page 1992, Mench et al. 1994, Mench et al. 1997, Sappin-Didier et al. 1997). Heavy applications of phosphate to polluted soils can reduce the amount of zinc dissolved in the soil solution by causing dissolved zinc to precipitate (Saeed and Fox 1979).
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Notes:
- a: pH < 6.5
- b: pH > 6.5
- c: Standard NFU 44-041 (July 1985)
- d: Ministry of Housing, Physical Planning and Environmental Conservation Report HSE 94.021, 1994
- e: Before using sewage sludge
- f: After the application of sewage sludge to the soil
- g: The concentration of Cu, Zn, and Ni at pH < 6.5; Other elements are the concentration at pH ≥ 6.0
- h: After the application of sewage sludge to the soil (USEPA Act) (USEPA 1993)
- i: As: extracted by 1M HCl, Cu and Ni: Extracted by 0.1M HCl; Hg, Pb, and Zn: total concentration.

Source: Chen et al. 1999
Some plant species (flowers, and trees with a high economic value) can be grown in polluted soils to remove trace elements, and as a way of continuing agricultural production on contaminated soils (Lee and Liao 1993, Lee and Chen 1994, Brooks 1997, Chen and Lee 1997a). Brooks (1997, 1998) reported that some plants are “super-accumulators” of heavy metals. He defined these as species which contain more than 0.1% (1,000 mg/kg) of copper, lead, nickel or cobalt in their dried tissues. In the case of zinc, a threshold of 1% (10,000 mg/kg) is proposed.

**Phyto-remediation Techniques**

Some plant species (flowers, and trees with a high economic value) can be grown in polluted soils to remove trace elements, and as a way of continuing agricultural production on contaminated soils (Lee and Liao 1993, Lee and Chen 1994, Brooks 1997, Chen and Lee 1997a). Brooks (1997, 1998) reported that some plants are “super-accumulators” of heavy metals. He defined these as species which contain more than 0.1% (1,000 mg/kg) of copper, lead, nickel or cobalt in their dried tissues. In the case of zinc, a threshold of 1% (10,000 mg/kg) is proposed.

**EVALUATION OF SOIL REMEDIATION FOR SOILS CONTAMINATED BY TRACE ELEMENTS IN TAIWAN**

Whether remedial action should be taken to treat contaminated soils, and if so, what measures should be used, is based on the following considerations (USEPA 1990, Adriano et al. 1997, Chen 1997, Iskandar and Adriano 1997, Lo and Che 1997, Pierzynski 1997):

- Short-term effectiveness;
- Long-term effectiveness;
- Reduction in the toxicity, mobility, or volume of the heavy metal concerned;
- Whether implementation is feasible;
- Cost;
- Compliance with government standards or guidelines;
- Overall benefit to the environment;
- Whether the measures are acceptable to the government; and
- Whether the measures are acceptable to local people.

A detailed evaluation of alternative ways of treating rural soils in Taiwan contaminated with cadmium and lead came to the following conclusions (Chen 1997, Lo and Che 1997):

- Chemical extraction methods can be used for sites where the soil contains medium levels of cadmium or lead.
- Chemical immobilization methods should be used for sites which are seriously contaminated with cadmium or lead.
- Engineering methods, involving the removal of polluted soil and its replacement by clean soil, can also be used for sites with serious cadmium or lead contamination.
- Engineering methods using the acid-leaching process can be used for sites with serious cadmium or lead contamination.
- Remediation with growing plants can be
used only on sites where contamination with cadmium or lead is very slight. Suitable plant species must be selected for polluted sites.

CONCLUSION

More than 40% of the rivers in Taiwan are moderately to heavily polluted, and have already lost any beneficial uses. Much of the agricultural land close to industrial complexes suffers from wastewater pollution. Contaminants include heavy metals, hazardous organic wastes and corrosive metal materials.

The levels of heavy metals in rural soils and crops in Taiwan have been investigated over the past 15 years. At least 787 ha are regarded as highly contaminated. Urban soils are also contaminated by heavy metals, especially cadmium, chromium, copper, nickel, lead and zinc.

There is no clear relationship between the concentration of cadmium in brown rice, and the amount of cadmium extracted from the soil by 0.1 M HCl. This means that the 0.1 M HCl extraction method is not suitable for predicting the uptake of soil cadmium and its presence in rice grain.

Exchangeable (or available) forms of cadmium and lead can be transformed into unavailable forms if the soil is amended with manganese oxide, calcium carbonate or zeolite. The concentration of cadmium in the soil solution, and levels of cadmium extracted by DTPA and EDTA, decreased significantly when the soil was treated with calcium carbonate. Treatments of zinc oxide, however, had no significant effect.

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