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Kuratorium für Technik und Bauwesen in der Landwirtschaft

Assessment and reduction of heavy metal input into agro-ecosystems

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Coordination

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Preface

In the latter years of the 20th century the public awareness of the problems associated with heavy metals in the environment increased following incidents like the cadmium induced "Itai-Itai disease" in Japan or the discovery of serious soil contaminations in mining areas and the health hazards associated with it. Furthermore, the widespread diffuse input of heavy metals into soils by atmospheric deposition or fertilisation raised concerns about the long-term implications for soil health and function, the quality of agricultural produce and the wider environment. Since then many measures have been implemented to reduce the pollution of air, soil and water and avoid or slow down the accumulation of metals in the soils and the food chain. Examples include the banning of lead in petrol or the use of low cadmium phosphorus fertilisers in agriculture. Furthermore, the implementation of waste avoidance strategies in many industry branches reduced the release of metals into the environment. Despite these efforts, the level of protection of the environment and the safety of human food and livestock feeds should still be improved.

It is well known that a considerable proportion of heavy metals inputs into soils are a consequence of agricultural activities. However, there are still many gaps in our knowledge of input pathways of heavy metals onto farms and subsequently into the soil. This is especially true in relation to the significance of the various input pathways compared with the total input, to the behaviour of metals in the soils, as well as to options for metal input reduction.

In view of the activities of the European Commission to develop a soil protection policy on European level, European co-operation in heavy metal related research gains an added importance. Against this background, the Concerted Action "Assessment and reduction of heavy metal inputs into agro-ecosystems" (AROMIS) was set up by the Association for Technology and Structures in Agriculture (KTBL) and 23 other institutions from across Europe, representing EU-25 Member States, Accession Countries and Associated States aiming to provide a cross national assessment of heavy metals in European agriculture.

Association for Technology and
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Dr. Heinrich de Baey-Ernsten

Executive Summary

Heavy metal accumulation in soils may have long-term implications for soil health and function, the quality of agricultural produce and the wider environment. Heavy metals may enter soils as a consequence of agricultural activities (e.g. the use of mineral fertilisers and organic residuals) or via non-agricultural inputs (e.g. atmospheric deposition). The relative importance of the various input pathways needs to be established, so that options for reducing overall metal inputs can be correctly targeted.

The main objectives of the AROMIS Concerted Action, which comprised 24 European research institutions, were to:

- Identify the input and output pathways of heavy metals in agro-ecosystems and their relative significance.
- Provide information on current legal regulations relating to heavy metals in agriculture.
- Describe possible measures for reducing heavy metal inputs and assess their potential effectiveness and practicality.
- Identify future research and technology transfer demands.
- Create contacts and links between European research institutions

A database was set up to collate all the data provided by the project partners on heavy metal inputs, legislation, research activities etc. A balance tool was also developed to calculate heavy metal balances for typical or model farms. Atmospheric deposition was found to be an important source of many heavy metals to agricultural land. Mineral fertilisers, in particular P-fertilisers, were an important source of Cd and sometimes contributed significantly to Cr and Ni inputs. Organic residuals such as composts, sewage sludge, or industrial wastes could be an important local source of many heavy metals. However at the national scale, they were less significant due to the relatively small land areas involved. For livestock farms, metal inputs were often dominated by imported livestock feeds supplemented with trace elements, especially Zn and Cu in poultry and pig farming. Disinfectant hoof baths for ruminants could also input substantial amount of Zn or Cu where used. Metal outputs with animal products such as meat, milk or eggs and via leaching or plant uptake were generally small compared with the inputs.

The input reduction measures considered in detail during the AROMIS project included:

- Reduced trace element supplementation of livestock feeds
- Control over the heavy metal content of mineral fertilisers
- Control over the hygienic use of metal products
- Alternatives to galvanised materials associated with livestock units

For some of these there are already control measures in place, although there are practical and economic reasons why these may not be the most suitable ways of protecting soils in the future. Alternative solutions may need to be found or consideration given removing the metal containing materials from the farm or preventing the contamination in the first place.

The effects of selected input reduction measures were assessed using data from model farms. Reductions in total farm inputs of up to 62 % for Cu and up to 49 % for Zn were achieved when reduced Cu and Zn supplementation was used in pig production. Use of an alternative to $CuSO_4$ reduced the Cu-surplus for the model dairy farm by around 36 %.

This project has highlighted the lack of reliable data to fully evaluate the input and output pathways of heavy metals in agro-ecosystems, metal behaviour in soils and changes in soil metal concentrations over time and has suggested topics for further research. To fully assess the potential for reducing heavy metals inputs into agro-ecosystems the following further research is suggested:

- Trace element requirements of livestock to cover modern genotypes and farm management practices.
- Investigation of alternatives to Cu for growth promotion in pig production
- Bioavailability of different trace element compounds and formulations
- Effective strategies for reducing contaminant inputs with mineral premixes
- Alternatives to ZnO and novel management practices to improve gut health and feed conversion of weaned piglets
- Management practices to improve hoof hygiene and reduce usage of Cu/Zn disinfectants.
- Development of prophylactic measures and alternatives to Cu fungicides.
- On-farm assessments of metal input reduction strategies and improved transfer of information on the options to reduce heavy metal inputs.

The AROMIS consortium advocates the creation of an European-wide network for heavy metal research and monitoring. This should link the leading agricultural research and technology transfer institutions, representing the main agricultural production regions in Europe and covering the range of conditions for agricultural production throughout Europe. An important instrument would be an European-wide network of monitoring and demonstration farms. This farm network should reflect the typical soil, climatic and management conditions in Europe and consider conventional as well as organic farming. The network could also provide a contribution to the developing European Soil Protection Strategy.

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List of abbreviations

µg	microgramme
ds	dry substance
dm	dry matter
g	gramme
ha	hectare
kg	kilogramme
L	litre
mg	milligramme
mm	millimetre
t	tonne
yr, a	year

Elements and compounds

As	Arsenic
BaO	Barium oxide
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
$CuSO_4$	Copper sulphate
K	Potassium
Mo	Molybdenum
Mn	Manganese
N	Nitrogen
Ni	Nickel
P	Phosphorus
Pb	Lead
Ti	Titanium
TiO_2	Titanium Oxide
V	Vanadium
W	Wolfram
Zn	Zinc
ZnO	Zinc oxide

Country codes

AU	Austria
BE	Belgium
CH	Switzerland
CZ	Czech Republic
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
NL	The Netherlands
NO	Norway
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
UK	United Kingdom

1 Introduction

1.1 Heavy metals in agriculture

All soils contain heavy metals, the concentrations depending on the nature of the soil parent material. Soils developing on basic or ultra-basic parent materials or black shales often contain elevated heavy metal contents (KUNTZE et al. 1991, WILCKE and DÖHLER 1995). Lower concentrations are found in soils based on sandstone, due to their high quartz grain content and low metal adsorption capacity (ALLOWAY 1995). The geogenic topsoil heavy metal contents are normally supplemented by an anthropogenic component from atmospheric deposition and cultivation practices. Inputs to soils from agricultural activity which are considered to be of particular importance are inputs of Cd and other metals with phosphorus fertilisers, and Cu and Zn inputs with livestock manure. Furthermore the continued use of sewage sludge, industrial wastes or compost might result in high metal inputs and to accumulation of metals in the soils. Locally, the intensive use of metal based fungicides in vineyards, fruit and potato growing plays an important role.

The soil-plant transfer of metals and the extent of leaching to the groundwater largely depend on the available metal fraction, which is predominantly determined by soil pH, clay content and organic matter (ALLOWAY 1995). For the heavy metals considered here, the available fraction normally increases with declining soil pH. However, broadly applicable conclusions concerning the leaching of heavy metals to the groundwater and the uptake into plants are difficult to draw due to the wide variations in soil properties and technical problems with a reliable measurement of leaching (WILCKE and DÖHLER 1995).

If certain levels of soil heavy metal concentrations are exceeded, the effect on the transfer into the groundwater or on plant uptake must be considered in addition to possible damage to soil functions, e.g. changes in the composition soil flora and fauna or a decline in microbial activity. A possible consequence might be unacceptable metal concentrations in food- and feedstuffs as defined in EU regulations and WHO recommendations. Thus, merely balancing soil inputs and outputs may not necessarily result in sufficient protection of agricultural eco-systems.

Whilst some of the heavy metals considered here are potentially toxic to plants and animals, they also play a role as essential trace elements. For example, Cu and Zn are required to maintain many physiological processes in plants and animals (NICHOLSON 2002).Trace elements are supplemented in livestock feeds if:

- the feed contains insufficient amounts of trace elements,
- the feed contains substances which have an detrimental effect on the utilisation of the trace elements or
- the elements occur in compounds which are not physiologically easily available.

In some cases trace elements are supplemented in excess of nutritional requirements to promote animal growth, e.g. the use of Cu in piglet rearing. While growth promotion is accounted for in feedstuff legislation, the use of elevated Zn concentrations in piglet diets to treat and prevent scour is only permitted on veterinary prescription. Trace element supplementation in excess of nutritional requirements is subject to ongoing discussion.

Chromium and Ni, although classified as essential trace elements, are not permitted additives to animal diets. Lead and Cd are considered to be undesirable substances in animal feed with maximum permitted levels fixed by the EC[1].

Only a small fraction of the metals from animal feed is retained in the animal body or transferred to products like milk and eggs (Schenkel 2002a); hence most of the metals are excreted and subsequently spread to the soils with the manure.

1.2 The AROMIS project

1.2.1 Objectives

The AROMIS project focused on the heavy metals cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) due to their relevance for soil protection issues. They are already subject to various legal regulations in legislation governing sewage sludge use, biowaste, feed additives and undesirable substances in animal nutrition (see chapter "Current legal situation in the European Union" for details).

The overall objective of AROMIS was to identify the contribution of agricultural activities to heavy metal inputs into agro-ecosystems, to draft strategies for input reduction and evaluate their efficiency, and generally to improve the availability of heavy metal related information in Europe, supporting the development of European soil protection related policies.

The main objectives of AROMIS can be summarised as follows:

- Provision of information on current legal regulations regarding heavy metals in agriculture.
- Assessment of the pathways of heavy metals into agro-ecosystems and evaluation of the significance of the various paths for the metal input and output.
- Description of technical and legal measures to reduce the heavy metal input and assessment of their effect regarding potential and the prospects of implementation in practice.
- Identification of future research and technology transfer demand.
- Creation of Europe-wide contacts between research institutions to link heavy metal related research activities in Europe and enhance the exchange of knowledge on ecological, economic, technical, and legal aspects.

1.2.2 General approach

The AROMIS consortium consisted of 24 institutions from 21 European countries representing 18 Member states of the European Union, one Candidate Country and two Associated States and was co-ordinated by the "Association for Technology and Structures in Agriculture", KTBL, in Germany (see figure 1-1, table 1-1). The project was divided into four sections:

1. Heavy metal database
The available data and background information concerning heavy metals in agriculture in the participating countries were collected. This included information on the sources of heavy metals, (e.g. the contents of heavy metals in feeds, fertilisers and organic residues), the relevant legal regulations on a European and national level and the research activities in this field.

2. Heavy metal balances
An essential part of the project was the compilation of heavy metal balances at a farm level, designed to illustrate the inputs, outputs and internal flows of heavy metals and enable the simulation of the effect of input reduction strategies. For this an MS-Excel based balance tool was developed which allows the calculation of farm level balances (see section 1.2.4.2). Balances were calculated for a number of selected countries where sufficient reliable data was available, using typical agricultural enterprises for animal and plant production in the relevant country or region.

Figure 1-1: Map of countries participating in the AROMIS project

3. Description and evaluation of input reduction measures
Based on the balance results and the available literature, the possible options for heavy metal input reduction were described. The legal and technical options for heavy metal input reduction presented here are restricted to agriculture and do not include other inputs not resulting from agricultural activities (e.g. atmospheric deposition). In addition to the reduction measures, requirements for future research and development were identified.

4. Future research demand
Identification of future research and development needs, derived from the assessment of the input reduction measures and the data gaps which became apparent when setting up the data base.

1.2.3 Heavy metal database

A database was set up based on the data collected on the different inputs and outputs of heavy metals in European agriculture. The metal fluxes considered correspond to those listed in table 1-2 in section 1.2.4.2. As well as information on heavy metal contents and loads, the database also provides farm gate metal balances for both animal and crop production. As the data availability in some of the participating countries is at present not sufficient to establish validated balances, only a selected number of representative model farms are presented in the database reflecting the most important production types in Europe. In addition, there is an overview of national and EU heavy metal legislation including, for example, threshold values or maximum application amounts for