Title:

Estimation of the balance of heavy metals in Romanian agro-ecosystems and research directions

Authors:

Iordache Virgil[a], Dumitru Mihai[b]

Affiliations:

[a] University of Bucharest, Department of Systems Ecology, Spl. Independentei 91-95, 050089 Bucharest, Romania, virgil.iordache@bio.unibuc.ro

[b] Institute of Soil Science and Agrochemistry, Blv. Mărăşti nr. 61, 71331 sector 1, Bucharest, Romania, mdumitru@icpa.ro

Abstract

In order to characterize to current state of Romanian agro-systems with respect to heavy metals pollution and to identify mitigation measure, we performed an extensive review of the existing data, literature, and policies. The following areas were covered: the context of the problem of pollution with heavy metals in agro-systems, the background concentrations and non-agricultural inputs (heavy metals concentrations in soils, atmospheric deposition), agricultural practices and related inputs (mineral fertilizers, animal wastes, pesticides, irrigation water, flood-related inputs, livestock feeds), runoff and erosion, leaching, biological products, and animal excreta and waste water. Based on these data a heavy metal balance for Romania was performed. According to the existing data the major inputs of metals to agricultural lands are by natural fertilizers and atmospheric depositions, and the major outputs occur by dumped animal wastes and plant food products. Research priorities are discussed.

Keywords: Heavy metals; Agriculture**;** Balance**;** Romania.

Content

Introduction

The problem of the pollution with heavy metals in agrosystems in Romania is framed by a context consisting of two elements.

1. the overall biogeochemical cycles of heavy metals in the natural and human

ecological systems of the country (the so called natural capital and socio-economic systems)

2. the overall deterioration of the agrosystems of the country

The first element of the context provides an idea of the relative importance of heavy metals pollution in agrosystems, as compared with the pollution of other types of ecological systems. It also makes explicit the external factors controlling the pollution of agrosystems (i.e. the factors originating in the connections between agrosystems and other natural and socio-economic systems). The second element of the context informs about the relative importance heavy metals pollution as compared with other types of deterioration occurring in the case of agrosystems.

Element 1. The national environmental strategy (MAPPM, 1996) offers a synthesis of the current national environmental problems. One aspect pointed out is the heavy metals pollution of water and soil in different geographic areas of Romania. The main causes of pollution is related to several industrial platforms and mining areas, as well as wastes disposal. Most of the intensive pollution is usually limited to the dispersal area around these platforms and mining areas, and affects all types of ecological systems, including socio-economic systems (human settlements). Agrosystems represent an important type of ecological system in the intensively polluted area, but not the only one. The main mechanisms involved in the pollution of ecological systems: is dispersal by air, by rivers, and direct disposal. The dispersal by air is responsible for the pollution of most affected agrosystems, while dispersal by rivers is responsible for floodplain and downstream river contamination (including the relatively few agrosystems located in the floodplain). Monitoring reports show also that rivers biota (Lower Danube River fish) have large concentrations of heavy metals far downstream the responsible industrial and mining sources (ICIM, 1999, INDD, 1999, Iordache et al., 2000), and sometimes even the abiotic compartments (Lacatusu et al, 1998). This downstream chronic pollution reflects all the sources from the Danube catchment, and by now there is no enough information allowing us to discriminate between the contribution of each country. Most of the studies concerning heavy metals pollution have adopted a sectoral approach (they have not envisaged the full complexity of the studied ecological systems). In particular, studies of soil pollution have dealt, with soil-plant systems, including litter, and only seldom animals (e.g. Lacatusu et al., 1997a). Information concerning other compartment have been extracted only from literature. Consequently, there is a lack of quantitative knowledge about the fluxes in which the different contaminated environmental factors (air, water, soil, biota) are involved, as well as about the cumulative and delayed effects in space and time. This sectoral approach is reflected also by the current monitoring system, with separate monitoring of the environmental factors by different responsible institutions, few communication between the involved actors, and separate strategies for improving the quality of the environmental factors (Varduca, 2002, Rauta et al., 1998, Cernatoni et al., 2002, Popescu and Vintila, 2002).

Element 2. An overall analyses of current priorities in soil protection is made in Dumitru et al. (2001). The analyses was based on an inventory performed on 12 millions ha of the total agricultural area of 14856800 ha. Table 1 summarizes the surfaces of agricultural fields affected by different limiting factors of the productive capacity. The Zn deficiency registered over 1.5 millions ha significantly affects the maize production. On the other hand, very aggressive effects are due to the pollution with heavy metals (especially Cu, Pb, Zn, and Cd) and SO2, identified mainly in the areas Baia Mare, Zlatna, Copsa Mica. Even if in the last years some industrial platforms have been closed (such as ROMFOSFOCHIM-Valea Calugareasca), and others have reduced their activities, soil pollution remains high also in areas such as Targu Mures, Turnu Magurele, Tulcea). In some of these areas there are documented toxicological (Dumitru, et al., 1996), and ecotoxicological (Vadineanu et al, 1991, quoted by Dumitru et al., 1996) effects of the heavy metals. Other approximately 700000 ha are covered with slight-moderately polluted soils (Lacatusu et al., 1992). In 1992 the area excessively polluted, 169242 ha, was smaller than in 2000 (200000 ha), and had as pollution causes those listed in table 2 (Vrinceanu et al., 1997). One can see that the excessive pollution due to agriculture plays minor role. However, agriculture may more important as a cause of slight-moderately polluted soils. According to Vrinceanu et al. (1997), soil pollution caused by agricultural technologies occurs either by strengthening of some negative natural physical and chemical characteristics of the soil (for example salt affection by salt waters or by the uncontrolled irrigation of soils with natural potential of salinization) or by the accumulation of the chemical substances used disease and pest control. Excessive fertilization has been another cause of soil pollution by technical means, especially the application of high rates of nitrogen fertilizers with high acidification potential and with high content of nitrate nitrogen. The deposition and application of the zootechnical wastes, of the sludge from city or industrial waste waters treatment plants is another source of soil contamination, when these operations are not carried out among the recommended limits for environmental protection (op.cit). It is worthy noting, as relevant for the input of metals by irrigation water, that the surface where irrigation infrastructure is available has continuously decrease from 1990 (3215800 ha) to 2000 (400000). In 2000 only 204200 ha have been irrigated (***, 2001b). The restoration of soils and landscapes quality (including as priority the rehabilitation of the soils heavily polluted with heavy metals) is evaluated as having a cost of ~25 billions Euro over 15-25 years (Dumitru et al., 2001).

In this context, it is not surprising that a detailed heavy metals balance at farm gate would not be possible to be computed at this stage (excepting for some experimental fields, with no relevance for the real farm systems), because of two basic reasons. Reason 1 relates to the sectoral approach dominating the research of metals biogeochemistry (which do not facilitate a focus on estimating fluxes connecting the agrosystems with other ecological systems), and is not the most effective in producing knowledge given a limited amount of financing for research. Reason 2 relates to the fact that there are other soil deterioration pathways as important as heavy metal pollution, which limited the local research funds dedicated to heavy metals pollution of agrosystems. Also, a balance at country level can be computed only with fragmentary data and by making assumptions which induce a high degree of risk to the decision made on the basis of these evaluations.

We will start now an analysis of each category of existing data.

Table 1 about here

Table 2 about here

1 Inputs

1.1 Background concentrations and non-agricultural inputs

1.1.1 Heavy metals concentrations in soils

The heavy metals concentrations in soil are comprehensively characterized, even before the start of the integrated soil monitoring system (Dumitru et al., 2000), by the mapping of the geogenic concentrations (e.g. Ianos, 1998, Lacatusu et al., 1993, 1994, 1997b, 2001, Mihailescu et al., 1986, 1988). These studies allowed the identification of areas with microelement deficiency, as well as of the areas with high natural background (the last ones are located mainly in mountainous areas of volcanic origin, with low relevance for the agrosystems). Table 3 present contents of potential polluting elements in top soil by main agricultural land uses and soil types.

Table 3 about here

1.1.2 Atmospheric deposition

Atmospheric deposition in Romania is monitored only in forest ecosystems, as part of the European specific monitoring network. However the fluxes analyzed in Romania include only S-SO_4, N-NO_3, N-NH_4, Ca, Mg, K, and Na (Barbu 2004, Barbu et al. 2004). For instances, the flux of S decreases from 16 kg/ha/year at low altitudes (~100m) to 8-10 kg/ha/year at altitudes above 1000m. The same pattern has been observed for Cl, N-NO_3, and N-NH_4. Average depositions of Ca, Mg, K, and N (in 1998-2002) were 16 kg/ha/year, 3, 6.7, and 4.9, respectively, with generally higher values in the southern part of the country, and important year to year variations. Quantitative data concerning heavy metals in air are available in what concerns emissions (Constantinescu, M., personal communication), but they cannot be indirectly used for assessing depositions due to the well known large scale atmospheric exchanges.

Indirect information concerning atmospheric deposition of heavy metals is provided by deposition models at European scale. For instance the Dobris report mention for Romania 0.5-1g/year of Cd over 80% of its surface, 0.2-0.5 g/ha/year over 17% of the surface and 1-2g/ha/year over 3% of the surface. The average values for Romania are, in the mentioned report, more or less similar with the other countries in the area, such as Bulgaria, and slightly lower than Hungary. If we look at independent data characterizing Hungary (Bozo, 1993, Meszaros et al., 1993), we see that values for Cd range from 1g/ha/year to 5.7 g/ha/year. This seems to confirm the predictions of the European scale models, and consequently we will use the average data characterizing Hungary adjusted by a fraction of 0.5 for a very rough assessment of deposition in Romanian soils.

On the other hand, it is known that the heavily polluted soils in the nearby of industrial platforms are polluted by air dispersal. However, direct quantification are not available in the literature.

1.2 Agricultural practices and related inputs

1.2.1 Mineral fertilizers

From a maximum of 1265299 t applied in 1986 (Dumitru et al., 2001), the amount of inorganic fertilizers have decreased in 2000 to 327537 t (***, 2001a), of which 88258t are P fertilizers, with known capacity of inducing heavy metals accumulation in soils. Mineral fertilizers have been applied in 2000 on 3724578 ha. The concentration of heavy metals in these fertilizers is unknown. In order to assess at least the magnitude order of the input by fertilizers, we will use an average of the values provided by studies performed in other European countries (Eckel and Dohler, 2001).

1.2.2 Animal wastes

In 2000 there were 21.4 cattle and 60.8 sheep and goats per ha of arable land, pastures and meadows, and there were 62.7 pigs per ha of arable land (***, 2001a). Table 4 provides an assessment of total animal wastes produced in 2000, including the used assumptions. Rauta and Dumitru (1986), estimated that in 1982 the pig and poultry wastes included 403849 t of N, 98154 t of P, and 228258 t of K. Jinga et al. (1990) estimated the quantities of waste water associated to animal raising at that date as being 53 mil m^3 from pigs, 15 mil. m^3 from cattle, 2 mil m^3 from poultry and 1.8 m^3 from sheep. We will characterize below the situation concerning the solid waste, the semiliquid wastes and the liquid wastes. Solid wastes refer to the sludge (which include both excreta and remnants of food), and in some cases to solid manure; liquid wastes refer to waste water (which include both diluted urine and substances phisico-chemically partitioned from the sludge); semiliquid wastes refer to fresh pig excreta. All the available literature reporting metals concentrations dealt with solid and liquid wastes (tables 5 and 7).

A high number of experiments were performed with quantities of animal *sludge* ranging from 10t/ha to 100 t/ha (e.g. Popa, 1964, Jinga, 1978, Stepanescu et al., 1978-1980, Ionescu-Sisesti et al., 1980, 1981, Dumitru et al., 1982, ***, 1981-87, Dumitru et al, 1993b). Up to 70 t/ha were found acceptable for pig sludge application over soil, but no less than 30 t/ha in order to obtain a significant increase in plant production. The quantity depended on soil type and culture. Nastea et al. (1983) recommended the application of 10 t of composted pig sludge / ha. In what concerns the cattle *solid manure*, 30t/ha of were found optimal (***, 1981-87). In a syntheses paper, Jinga et al. (1990) recommend the application of 20-30 t of waste / ha, for obtaining a fertilizing effect with a duration of 1-2 years.

Jurubescu (1977) recommends an average of 50m^3 of *semiliquid wastes* / ha (20–75 m^3

depending on soil and culture). The recommendations concerning the use of *waste water* are more variable, depending on the quality of the water and on the climatic area (Ionescu-Sisesti et al., 1979). Jinga (1971) reports a miximum of 7500 m^3/ha in the studied case, and Jinga et al. (1984) recommend 2250-3875 m^3/ha, with no more than 500 m^3/ha in one application. Frequently it is recommended a dilution of the waste water with normal irrigation water (e.g. Dumitru et al., 1982a, 500-800 m3/ha, 1:5 diluted with normal water).

15812625 t of natural fertilizers were reported as applied over 647200 ha in Romania in 2000 (***, 2001a), which is below our estimation of animal waste production. No details separately concerning the application of solid, semiliquid and liquid animal waste are currently available at national level. For computing metals input by natural fertilizers we will use an average of the values mentioned in table 5.

1.2.3 Industrial and sewage sludge and composts

The total production of industrial sludge in 2000 was 2.5 milion t, of sewage sludge 0.54 milion t, and of urban domestic wastes 8.15 milion t (***, 2001a, Badea et al., 2003). In the 80-90 years a number of studies investigated the application of industrial and urban sludge (table 6, including concentrations of metals in these media). Dumitru et al. (1984) recommended the application of 50-60 t of industrial sludge / ha in the studied case, and Blaga et al. (1989) recommends the application of 60-80 t of industrial sludge /ha only after improving the technology in order to reduce the concentration of metals. Recently experiments with sewage sludge restarted (Borza and Radulescu, 1998), in order to optimize the application solution for specific cities.

Table 4, 5, 6, 7 about here

Even if the application of sewage sludge is not yet regulated , ICPA (National Institute for Soil Science and Agrochemistry), which is involved in advising and approving the application of sewage sludge in case by case situations, currently uses the following recommendations (Stefanescu and Dumitru, 1991):

- 6-10 t dm / ha every 3 years (30 t sewage sludge / ha with 65 % humidity every three years) or
- 10-20 t dm / ha every 5 years (50 t sewage sludge /ha with 65 % humidity every 5 years).

Maximum acceptable metals concentrations in the applied sewage sludge are (Stefanescu and Dumitru, 1991, in micrograms / gram dri weight): As 10, Cd 10, Co 10, Cr 500, Cu 500, Mn 1200, Hg 10, Mo 20, Ni 100, Pb 300, Se 14, Zn 200. Other factors taken into accounts when applying sewage sludge are the soil type, the type of culture, the underground water level, and the distance from the nearby human settlement.

Currently sewage sludge are applied only over 10-20000 ha around the major cities Pitesti, Suceava, and Timisoara (Borza and Radulescu, 2000). Badea et al. (2003) estimate that 3% of the total sewage sludge production is used in agriculture, which is 16200 t for 2000 year.

In 1971 the composition of the domestic urban waste of Romania included 40-70 % as vegetation and organic materials (Jianu and Alexandrescu, 1971). The percent decreased since then down to 39% as food remnants in 2000 (Badea et al., 2003) but the potential for preparing urban composts for agricultural use remained high. RDNIEP (Research and Development National Institute for Environmental Protection) is involved in an ongoing European project dealing with the development of a standard methodology for characterizing the composition of urban domestic wastes. Currently no composts are prepared on a large scale, and consequently urban composts are not used in the agriculture. However, one of the objectives of the strategy for wastes management is the reduction of biodegradable wastes sent to waste deposits, and activities of compost preparation and distribution to agriculture are explicitly stated (Badea et al., 2003).

In the 80^{s} a number of experiments were done for preparing such compost and applying it in the field (Dumitru et al. 1991, 1993a, Vijiiala et al., 1994b). Data concerning metals concentrations are presented in table 5.

1.2.4 Pesticides

3870 t of herbicides, 1240 t of insecticides and 432 t of fungicides have been applied in 2000 over 4650110 ha (***, 2001a). No data concerning the concentration of heavy metals in pesticides are available in the literature. Cu show the highest average concentration in the soil of vineyards (table 1), which might be due to the input related to applications of protective substances. However, these concentrations are rather low compared to other European countries, and not very much different from those found in other land uses types.

1.2.5 Irrigation water

As mentioned in the introduction, the areas irrigated have strongly decreased in the last years. Data on heavy metals concentrations in the irrigation water are not available. An assessment of the input can be done using the concentrations stipulated for water of 2nd

class of quality, which is acceptable for irrigation, and an average water input of 3000 m^3/ha/year. It is worthy noting that the lack of irrigation infrastructure impinges also on the utilization of waste water as fertilizer, because, as we have seen, frequently a dilution is needed.

1.2.6 Flood-related inputs

This type of input is highly relevant only for the Danube floodplain, especially in the context of the current reconstruction plans (Vadineanu et al., 2000). The patterns of metals distribution in Danube floodplain ecological systems have been recently analyzed (Iordache et al., 1998, Neagoe et al., 2000), as well as the fluxes associated with the flood and anthropic use (Iordache, 2002a). The net retention of metals in the floodplain landscapes was in the range of 6.4-22.9 kg/ha/year for Cu, 6.7-50 for Zn, 2.3-17.4 for Cr, 2.3-16.9 for Pb, and 0.053-0.168 for Cd, depending on the landscape type. This retention was mainly due to mechanical sediment filtration. However, a net export of the dissolved forms of Zn, Cr, and Cd was remarked, due to biological and physicochemical process involving the flooding water during the flood. Because of the ecotoxicologial importance of dissolved metals, an assessment of the potential importance of this export after an eventual extensive restoration of the floodplain was done (Iordache, 2002b), leading to the conclusion that the restoration would not raise problems from this point of view more than the current natural systems, because the soils from the diked areas (used as agricultural land since the 60^s) are not significantly different in terms of heavy metals, from the not diked soils of the Danube floodplain. At this stage, we will not take into consideration the inputs of heavy metals related to floods when assessing the balance, due to the low percent of agrosystems in the current Danube floodplain.

1.2.7 Livestock feeds

Only one source related to inputs of metals by livestock feed was found available in the literature (Gatlan et al., 1998). These source states that the concentrations in animal feeds analyzed in the period 1996-1998 (279 samples, as part of the sanitary control process) have not been higher than those acceptable at the that time (3 ppm for Cu, 50 ppm for Zn, 0.5 ppm for Pb, and 0.1 ppm for Cd). Thus, the flux associated to animal feeds cannot be assessed. However, the input of heavy metals in livestock feeds is to some extent reflected in the animal manure input, which we have seen that can be estimated to some extent.

2 Outputs

2.1. Runoff and erosion

No data of runoff fluxes or superficial underground flows are published. Erosion by water and land sliding are responsible for an estimated average of 13.3 t/ha (range 3.2 - 41.5 t/ha) soil losses (Dumitru et al., 2001). Quantification of erosion by wind is not available. Using this average flux and the surfaces affected by erosion by water and land sliding we would obtain a soil output of 126 milion t, which is 2-3 times higher than the current annual discharge of sediment into the Black Sea by the Danube river (Panin et al., 1996). Consequently, the average erosion rate of the 6300000 ha suffering this process might lower, or an important buffering of the fluxes occur transversally and longitudinally in the river basins, and we cannot estimate a realistic flux of metals by this mechanism.

2.2 Leaching

The available literature concerning leaching was limited to Barbu et al. (2004). The estimated fluxes (average values for 1998-2000 period) were the same as in the case of atmospheric deposition. Leaching of sulphur below 60cm depth ranged between 1 kg/ha/year (at altitudes lower than 500m), and 7 kg/ha/year (at higher altitudes). At low altitudes sulphur had an accumulation trend in the soil, while at high altitudes the output was equal or even higher the input due to atmospheric depositions. The same pattern was noticed in the case of chloride and N-NO3, but not in the case of N-NH4, for which the leaching were always smaller than the atmospheric deposition. For total nitrogen the mentioned pattern applied as well, with less than 1kg/ha/year leaching at low altitudes. It is worthy noting that in 2000, a year with fewer than average precipitation, there was no leaching at all in the sites located at low altitudes (Barbu et al. 2004).

From the above information we can conclude, based on the reasonable assumption that the concentrations of heavy metals in the leaching water are smaller than those of S-SO_4, that heavy metals fluxes are probably low at low altitudes (where the agrosystems are located) below 1 kg/ha/year. This is also indirectly pointed out by the fact that the analysis of underground water quality (MAPPM, 1996) shows contamination problems only in the case of N-NO_3, to a smaller extent P-PO_4 and organic pollutants.

2.3 Biological products

Estimations of the fluxes associated with biological products are available in special cases related to experimental fields. Most of the already cited literature describing experiments with sludge, composts, manure, presents also the vegetal production enhancement and its quality in terms of metals concentration. However, no study has been published with regard to a real farm system. The main plant food products (***,

2001) had 20508300 t in 2000 (this amount does not include the residual part of the plants, used in many cases for other purposes than human food), and the main animal food products had 1924300 t (residual products also not included). Using the acceptable concentrations for food products, one can compute the output of heavy metals by food products.

Plant and food products are regularly analyzed for heavy metal concentrations as part of the sanitary control (Dumitrescu et al., 1979, Popa and Stanescu, 1981). However, these data are not usually published, and when they are published the results are presented no actual concentration are shown, but only the situation related to the acceptable threshold values feeds (Gatlan et al., 1998, Vincu et al., 1998). For instance, from 2578 meat samples analyzed in two counties from 1996 to 1998, only two samples (beef kidney, 1.5 ppm Cd) had concentrations higher than the acceptable values already mentioned in the subchapter concerning livestock feeds (Gatlan et al., 1998). The same authors cite Fantana (1998) as pointing out the need for geographically specific monitoring of food quality assisted by computer. From a different, nutritional, perspective, Vlad et al. (2000), publish a macro and micronutrients data set for the case of vegetal food in a limited geographic area of Romania. For computing the balance we will use the acceptable limits of heavy metals in animal food in 2000 (0.1 ppm Cd, 0.5 ppm Pb, 3 ppm Cu, and 50 ppm Zn, based on The Health Ministry Order 611/1995, no longer in use in 2003), and the acceptable limits in plants mentioned by Vrinceanu et al., 1997 (15 ppm Cu, 100 ppm Zn, 10 ppm Pb, 1 ppm Cd). This will be an overestimation of the output fluxes mediated by food products in the case of these metals, if we consider that the food products had concentrations below the acceptable limits. On the other hand, neglecting the residual products will induce an underestimation of the overall fluxes mediated by biological compartments. Concentration of Mn, and Cr in plant food products will be estimated according to Vlad et al. (2000), and that of Co according to ***, 1981-87.

2.4 Animal excreta and waste water

According to our estimations 28359882 t of animal excreta are produce, while just 15812625 t are applied as natural fertilizers. As long as it is stored outside of the agricultural area, the difference can be considered as an output. But it is more likely to be stored in the nearby of the animal farms. They might be responsible for the 1149 ha excessively polluted as a result of animal wastes application (table 2). If we consider that formally this area is inside the agricultural land, we can not consider the 12547257 t of animal wastes as an output. However, if we consider that this is in fact a flow with origin in the 14329900 ha of not permanent cultures which sustain the animal raising (with the underlying assumption that the animal feed metal import at national scale is not higher than the export), and going to the 1149 ha of excessively polluted sites, we can consider this flow at least as a very important internal flow at national scale. At this stage of the national balance we will consider, for simplification, and taking into consideration the very small surface of the excessively polluted sites (0.006% of the total) that the flux of animal wastes not used as fertilizer is actually an outflow from the total agricultural area.

There is also a production of waste water, estimated at 88790426 m^3, which we have seen that cannot be applied in the field as fertilizer without dilution in the frame of a functional irrigation system. Even if this water would be dumped on the excessively polluted sites, it is very likely that it will leave in some way the land towards aquatic systems or wetlands, either by leaching or by runoff. More probably this water is released in wetlands or even aquatic system (either directly or by a sewage system). Consequently we will consider the animal waste water as an output. It will be a partial double counting here in terms of amounts, because part of the quantity of waste water is due to urine, which has been already included in the animal wastes.

3 Heavy metal balance for Romania

Figure 1 presents a highly simplified homomorphic model used for computing the balance for the agricultural lands of Romania. Table 8 includes the values of the fluxes and the resulting net blance.

Figure 1 about here

The assumptions underlying the evaluation of the fluxes have been already presented in the case of each analyzed media. According to the resulted balance, the major inputs of metals to agricultural lands are by natural fertilizers and atmospheric depositions, and the major outputs occur by dumped animal wastes and main plant food products. Several aspects which would presumably influence the above conclusions have been completely neglected, namely:

- plant food products does not include the residual part of plants, which in many cases is used as fodder in animal farms. Thus, the export by plant products is much underestimated. Normally this export should be higher than the input by natural fertilizers, if the metals in animal feed has their main origin in the local plant products.
- how much of the output by dumped animal wastes and main animal food products is originating in animal feed (from industry and trading) with foreign origin and in contamination within the animal farm. We have assumed that all this flux has origin

in local agricultural land (by plant food products transferred to animal farms by industry and trading). If the foreign animal feed is important, the outputs by wastes are over estimated.

- how much of the input by natural fertilizers has different origin than animal feed produced by using local plant products.
- how much export by erosion takes place. This is probably a major export pathway in Romania. From this point of view the output is strongly underestimated
- what is the real value of atmospheric deposition of metals in Romania.

Because the surfaces on which some inputs apply are in fact much smaller than the total surface of the agricultural land, and because of the high variability in space of the atmospheric depositions, one can expect very large differences from this balance, at regional and local level.

Table 8 about here

4 Research directions

One can identify two kinds of research priorities:

- one is related to strictly improving the possibility for computing a metal balance for the agricultural land at different level (from farm to national level),
- and the second one is related to putting the problem of heavy metals pollution of the agricultural land in the broader context of heavy metals biogeochemistry and ecotoxicology at landscape level, and of the diversity of problems related to agricultural land, and more generally, to land use.

Table 9 present the first kind of research priorities. In what concerns the second kind of priorities, in the introduction, where the context of the analyzed problem was described, we have pointed out the main limitations in heavy metals research in Romania, as linked to the dominant sectoral approach. It has been also shown that heavy metals pollution is only one of problems relevant for agrosystems. Thus, if one would be to identify the main research priorities from this integrating perspective, these would be:

1. research programs in landscape biogeochemistry, nutrition science and ecotoxicology.
2. integrated approach of land use problems in order to assess the sustainable regional development

Figure 2 presents (after Iordache 2002a) the possible co-ordinates of a research program relevant for the first direction, which would be extremely useful to be developed in the highly polluted landscapes of Romania, by a consortium of national partners.

To follow the second direction one would have to develop tools and method as part of the decision support system for the codevelopment of the natural capital and socio-economic systems (Vadineanu, 1999), tools able to surpass the current sectoral decision making and decision support. It has been advocated such an approach for instance in the case of the national monitoring system (Iordache, 2002c, d) or for the risk assessment regulation (Iordache, 2002e).

Table 8 about here

Figure 2 about here

Acknowledgements

This study was performed in the frame of the EU project AROMIS (QLK5-CT-2000-00670), and of the projects 31012, 31043 / 2007 and 52175/2008 financed by the national agency CNMP.

References

1. ***,1981-87, Research reports, ICPA, Bucharest (in Romanian)
2. ***, 1988, Agricultural bulletin, MAIA nr. 5-8 (in Romanian)
3. ***, 2001a, Statistic annuary of Romania, Romanian Government. (in Romanian)
4. *** (2001b). Statistical data for the Romanian Environment, Romanian Government, (in Romanian)
5. Badea, A., T. Apostol, C. Marculescu, A. Atudorei, 2003, Aspects of the Romanian strategy for waste management, The Environment, 1, 25-37 (in Romanian)
6. Barbu, I., C. Iacoban, I. Popa, 2004, Modelling of pollutant fluxes in the atmosphere of the main Romanian forest types, ICAS Annals, 45: 187-197 (in Romanian)
7. Barbu, I., 2004, Space-time variation of pollutants concentration in precipitations over Romanian forests, Research report, ICAS Experimental Station, Campulung Moldovenesc (in Romanian)
8. Blaga, G., S. Nastea, M. Dumitru, V. Miclaus, L. Blaga, T. Lenditan, 1989, Studies concerning the use of sewage sludge for the improvement of soil fertility, Proceedings of the National Conference for Soil Science, Bucharest, 26A, 115-121 (in Romanian)
9. Borza, I., and H. Radulescu, 2000, Metal elements transfer in the soil-plant system as a result of town mud distribution on agricultural land, Proceedings of 4rd international symposium on "Metal elements in Environment, Medicine, and Biology", Timisoara, Romania, 71-74
10. Bozo, L., 1993, A legkori nehezfemek ulepedese Kelet-Europaban, MTA Agrartud. Oszt. Taj., Akademiai Kiado, 90-92 (in Hungarian)
11. Cernatoni, A., I. Varduca, E. Mehedintu, 2002, Elements for the characterizating the

pollution with heavy metals by an integrated monitoring of large catchments, ICIM Annals, Bucharest (in Romanian)

12. Dumitrescu, M., Z. Barduta, A. Sepeteanu,1979, Methodology for controlling the food quality, Publ. I.I.S.P, Bucharest (in Romanian)
13. Dumitru, M.,1983, Studies concerning the control of soil pollution by waste water and sludge resulted from pig farms. PhD Thseses, Faculty of Agriculture, USAMVB, Bucharest, (in Romanian)
14. Dumitru, M.,1991, The evolution of soil under the pressure of waste waters, ICPA Annals, Vol L, 247-259 (in Romanian)
15. Dumitru, M., C. Ciobanu, S. Carstea, A. Manea, 2001, Aspects concerning the management strategy of Romanian soil resources, Proceedings of the 30th national conference in soil scince, 30c, 7-19 (in Romanian)
16. Dumitru, M., C. Rauta, E. Gament, M. Damian, E. Dumitru (1993a). The fertilising influence of compost on soil and agricultural production ICPA Annals, Vol LII, 294-302 (in Romanian)
17. Dumitru, M., C. Rauta, E. Gament, M. Damian, I. Calciu, E. Dumitru, E. Dancau, (1994). Studies on the optimal crop structure for soils fertilized with sewage sludge, Proceedings of the national conference in soil scince,, Tulcea, 28E, 163-230 (in Romanian)
18. Dumitru, M., C. Rauta, M. Rusu, P. Gus, E. Gament, D. M. Motelica, E. Dumitru, (1996), The ecological restoration of soils contaminated with heavy metals in Zlatna are, Research report, ICPA, Bucharest (in Romanian)
19. Dumitru, M., C. Rauta, M. Vijiiala, E. Gament, M. Damian, E. Dumitru (1993b). The influence of sewage sludge on soil and agricultural production, ICPA Annals, Vol LII, 285-293 (in Romanian)

20. Dumitru, M., Ciobanu C., Motelica D. M., Dumitru Elisabeta, Cojocaru C., Enache Roxana, Gament Eugenia, Plaxienco Doina, Cristina Radnea, St. Carstea, Alexandra Manea, Nicoleta Vranceanu, I. Calciu, A. M. Mashali (2000). Atlas of soil quality monitoring in Romania, Ed. GNP, Bucharest, Romania, 53 pp + 24 maps (in Romanian)

21. Dumitru, M., D. Sandoi, V. Radulescu, S. Nastea, F. Dumitrescu, M. Damian, E. Gament, F. Alexandrescu,1990, Agricultural bulletin, nr. 3 , Bucuresti (in Romanian)

22. Dumitru, M., E. Dumitru, E. Gament (1982a). Methodology for using in an environmental safe way the wastes from pig farms, communication at the national symposium “Perspectives in agriculture”, Bucuresti (in Romanian)

23. Dumitru, M., E. Dumitru, S. Nastea, E. Gament, M. Damian, F. Dumitrescu (1991). Posibilitati de valorificare agricola a compostului obtinut din resturi menajere, Analele ICPA, Vol LI, 261-283 (in Romanian)

24. Dumitru, M., I. Plesa, I. Magdalina, I. Jinga, A. Teodoriu (1989b). Bulletin for agricultural managers, Ministry of Agriculture and Food Industry, nr. 4 (in Romanian)

25. Dumitru, M., L. Sestan, E. Gament, M. Damian (1993c). The influence of the fertilization with pig farm sludge on the chemical characteristics of soil, Scientific papers of the Research Station for Irrigated Croos, vol. X, 141-147 (in Romanian)

26. Dumitru, M., S. Nastea, C. Rauta, E. Dumitru, M. Damian, E. Gament, G. Blaga, S. Petrica, G. Ciobanu, F. Bulete (1989c). Bulletin for agricultural managers, Ministry of Agriculture and Food Industry, nr. 8 (in Romanian)

27. Dumitru, M., S. Nastea, C. Rauta, E. Gament, M. Damian, E. Dumitru, I. Jinga, M. Majiala (1989d). Bulletin for agricultural managers, Ministry of Agriculture and

Food Industry, nr. 6 (in Romanian)

28. Dumitru, M., S. Nastea, C. Rauta, F. Dumitrescu, M. Damian, E. Bugeac (1984). Testing the potential use of Victoria city sewage sludge in agriculture, Soil Science, 3, 65-76 (in Romanian)
29. Dumitru, M., S. Nastea, C. Rauta, L. Brutaru, F. Dumitrescu, M. Damian, E. Buceag, E. Gament (1986). The influence of sludges and composted sludges on soil chemical properties, in “Using sewage sludges and waste waters from animal farms in agriculture”, Institute for Soil Science and Agrochemistry Press, Bucharest, 291-294 (in Romanian)
30. Dumitru, M., S. Nastea, C. Rauta, M. Damian, E. Gament, I. Jinga, I. Borza, V. Stefan, G. Stefanic, N. Iga, E. Rasuceanu (1989a). Bulletin of the Academy for Agriculture and Silviculture, nr 18, Bucharest (in Romanian)
31. Dumitru, M., S. Nastea, C. Rauta, V. Ionescu-Sisesti, S. Cirstea (1982b). The Use of zootechnical wastes in agriculture, Institute for Soil Science and Agrochemistry Press, Bucharest (in Romanian)
32. Eckel, H., H. Dohler (2001). Assessment and reduction of heavy metal input into agro-ecosystems, report of the first AROMIS meeting, KTBL, Darmstadt, Germany
33. Gatlan, D. M., O. Draganescu, N. Fantana, V. Precob, M. Vincu, I. Gogoasa (1998). The study of the potential toxic metal content in animal feed and pork, beef and mouffon in Timis and Caras county, Proceedings of 3rd international symposium on "Metal elements in Environment, Medicine, and Biology", Timisoara, Romania, 213-216 (in Romanian)
34. Ianos, Gh. (1998). Sources and concentrations of heavy metals in S-W Romania, in “Metal Elements in Environment, Medicine and Biology, Proceedings of the 3rd International Symposium, Timisoara, Romania, 225-230

35. ICIM (1999). The monitoring of Danube River and Black Sea in relation to the consequences of the Yugoslavian conflict, Scientific report, National institute for Environmental Protection - ICIM, Bucharest, Romania, 86pp (in Romanian)

36. INDD (1999). Investigation of the toxic substances bioaccumulation and bioconcentration in organisms of the Danube Delta Biosphere Reserve, Scientific Report, National Institute for Danube Delta, Tulcea, Romania, 48pp (in Romanian)

37. Ionescu-Sisesti, V., N. Iga, S. Jarnea, V. Ghedesim, I. Guran, S. Nastea, S. Cirstea, C. Comaniuc (1979). Use of waste water for irrigation, Bulletin of the Academy for Agriculture and Silviculture (in Romanian)

38. Ionescu-Sisesti, V., P. Papacostea, G. Stefanic (1980). Compost use in agriculture, Scientific and Encyclopedic Press, Bucharest (in Romanian)

39. Ionescu-Sistesti, V., S. Nastea, C. Rauta, I. Jinga, S. Cirstea, M. Dumitru, M. Vijiiala (1981). Conditions for using waste sludges and waters in agriculture, Journal of Crops Production, 8-9 (in Romanian)

40. Iordache V., C. Postolache, N. Mihailescu, A. Neagoe, G. Ignat, S. Cristofor, A. Vadineanu (1998). Distribution patterns of metals in sediments of the Lower Danube System, Proceedings of the 3rd International Symposium on Metal Elements in Environment, Medicine and Biology, 45-53

41. Iordache, V, A. Neagoe, A. Cernatoni, M. State, T. Altorfer, E. Preda, S. Cristofor, A. Vadineanu (2000). Heavy metals in the Danube floodplain related to the Yugoslavian conflict, In: Proceedings of the 5th Symposium on Environmental Contamination, Prague, Czech Republic, CD-ROM format (7 pages)

42. Iordache, V. (2002a). Ecotoxicology of heavy metals in the landscape of Small Island of Braila, PhD Theses, University of Bucharest, Departement of Systems Ecology, 290 pages.

43. Iordache, V. (2002b). Preliminary assessment of the pollution risk associated with the restoration of the Danube floodplain, Proceedings of the 5th International Symposium on Metal Elements in Environment, Medicine and Biology, 211-219

44. Iordache, V. (2002c). The difficulties in assessing the effects of the Yugoslavian conflict in the Lower Danube River System pointed out the need for improving the monitoring system, J. Env. Protection and Ecology, 4, 557-563

45. Iordache, V (2002d). The coordinates of a systemic monitoring in Romania, The environment, 63-73 (in Romanian)

46. Iordache, V. (2002e). Opportunities for optimizing the risk assessment procedure, Annals of the scientific session "Environment and future" National Institute for Environmental Protection, Promotal Press, Bucharest, 213-220 (in Romanian)

47. Jianu, N., A. Alexandrescu (1971). Collection, neutralization and agricultural use of domestic and industrial wastes,Ceres Press, Bucharest (in Romanian)

48. Jinga, I. (1971). Research on the value of pig farms waster water as irrigation water, National Agronomic Institute Bucharest, PhD theses (in Romanian)

49. Jinga, I. (1978). Achievements and future directions in technologies for waste water and sludges use in agriculture and food industry, Realizari si orientari in tehnologia de valorificare a namolurilor si de epurare a apelor provenite de la crescatoriile de animale, sectorul avicol si industria carnii, Agricultural National Pedagogical Press, Bucharest(in Romanian)

50. Jinga, I., I. Plesa, M. Dumitru (1990). On eliminating the polluting effect of organic waste from commercial pig-raising complexes by agricultural use, The Environment, vol. I, nr 2, 37-39 (in Romanian)

51. Jinga, I., V. Ionescu-Sisesti, Al. Teodoriu, M. Dumitru, V. Bica-Pepii, E. Dumitru (1984). Potential use of pig farms waste waters in irrigation, in "Current problems

water protection and treatment in Romania", Vol. V, Timisoara, 33-36 (in Romanian)

52. Jurubescu, V. (1977). Recycling of zootechnical residuals, CERES press, Bucharest (in Romanian)
53. Lacatusu, R., C. Grigoras, G. Gheorghiu, S. Carstea, M. Lungu, C. Ulvoczi (1998). Heavy metals in soil and water of some strictly protected areas of the Danube Delta Biosphere Rezerve, Mengen und Spuren Elemente, 18, 165-172
54. Lacatusu, R., C. Rauta, B. Kovacsovics, M. Lungu, A. Mihailescu, I. Creanga (1994). Concentrations of heavy metals in the agricultural soils of the Eastern part of Subcarpathians, Getic Plateau, and Northern Central Romanian Plain, Publication of the Romanian National Society for Soil Science, 28A, 171-186 (in Romanian)
55. Lacatusu, R., C. Rauta, B. Kovacsovics, M. Lungu, G. Ianos, A. Mihailescu (1993). Heavy metals concentrations in Banat agricultural soils, Soil Science,1-2, 3-16 (in Romanian)
56. Lacatusu, R., C. Rauta, D. Plaxienco, V. Blanaru, M. Toti, M. Dumitru (1992). Soil pollution by industrial emissions and by intensive agricultural techniques, Proceedings of the Symposium "Links between human health and food pollution degree, Bucharest, 110-112 (in Romanian)
57. Lacatusu, R., C. Rauta, I. Risnoveanu, M. Lungu, B. Kovacsovics, G. Ianos, D. Tarau (1997b). Pedogeochemical maps of the Banat-Crisana Plain, Soil Science, XXXI, 1, 71-86 (in Romanian)
58. Lacatusu, R., M. Lungu, B. Kovacsovics, I. Risnoveanu (2001). Lead concentration in Moldavian soils, Proceedings of the 30th Soil Science National Conference, vol 30c, 213-223 (in Romanian)
59. Lacatusu, R., N. Avram, C. Rauta, M. Lungu, S. Carstea, B. Kovacsovics, M.

Serdaru (1997a). Lead in soil plant system within the Copsa Mica polluted area (Romania), Mengen und Spurenelemente, 17, 104-112

60. MAPPM - Ministry of waters, forests, and environmental protection (1996). Environment protection strategy, RAMO press, Bucharest

61. Meszaros. E., A. Molnar, Zs.. Horvath (1993). A mikroelemek legkori ulepedese Magyarorszagon, Agrokemia es Talajtan, 42, 229-242

62. Mihailescu, A., C., Rauta, P. Andar, G. Neata (1988). Geochemical distribution of heavy metals in Transylvanian soils, Annals of the National Institute for Soil Science and Agrochemistry, vol. XLIX, 339-361 (in Romanian)

63. Mihailescu, A., C., Rauta, R. Lacatusu, E. Buceag, F. Dumitrescu, P. Andar (1986). Pedogeochemical soil distribution in the North-West of Romania, Annals of the National Institute for Soil Science and Agrochemistry, vol. XLVII, 265-279 (in Romanian)

64. Nastea, S., M. Dumitru, C. Rauta, F. Dumitrescu, M. Damian (1986a). The characteristics of residual products from industrial pig farms, in "Using sludges and wastes for plant production", National Institute for Agrochemistry and Soil Science Press, 51-60 (in Romanian)

65. Nastea, S., M. Dumitru, C. Rauta, F. Dumitrescu, M. Damian, E. Buceag, E. Gament (1986b). Influence of the irrigation with pig farms waste water on soil properties, in "Using sludges and wastes for plant production", National Institute for Agrochemistry and Soil Science Press, 283-290 (in Romanian)

66. Nastea, S., V. Ionescu-Sisesti, C. Rauta, P. Papacostea, G. Stefanic, I. Jinga, M. Dumitru (1983). Technologie zur Kompostierung von Schweinegulle und der Einfluss des Kompostes auf die landwirtshaftlische Produktion, Tag.-Ber. Akad. Landwirtsch.-Wiss, DDR, Berlin

67. Neagoe A., V. Iordache, T. Altorfer, M. Pescaru, A, Vadineanu (2000). Metals in plants of Danube floodplain: deficiency or excess ?, Proceedings of the 4th International Symposium on "Metal elements in Environment, Medicine and Biology", Timisoara, Romania, 14-28 (in Romanian)

68. Panin, N., M-T. Gomoiu, G. Oaie, S. Radan (1996). Researches on the north-western Black Sea carried out by Romanian Centre of Marine Geology and Geoecology during 1995 within the EROS 2000 project, GEO-ECO-MARINA, 1, 90-113

69. Popa, G., V. Stanescu (1981). Sanitary control of animal food products, Didactic Press, Bucharest, Bucuresti (in Romanian)

70. Popa, M. (1964). Preliminary study on the use of raw and processed sludges in agriculture, Research report, Institute for Hydrotechnical Reseasrch (in Romanian)

71. Popescu, E., F. Vintila (2002). National assessment of groundwater vulnerable to pollution, Annals of the scientific session “Environment and future” National Institute for Environmental Protection, Promotal Press, Bucharest, 127-130 (in Romanian)

72. Rauta, C., M. Dumitru (1986). Fertlizing value of zootechnical rezidues, in "Using sludges and wastes for plant production", National Institute for Agrochemistry and Soil Science Press, 13-29 (in Romanian)

73. Rauta, C., M. Dumitru, C. Ciobanu (1998). Soil monitoring in Romania, vol. I si II, National Institute for Agrochemistry and Soil Science, Publistar Press, Bucharest (in Romanian)

74. Rauta, C., S. Nastea, M. Dumitru, S. Cirstea, P. Papacostea (1980). Using wastes as amendments for soils, Ministry of Agriculture and Food Industry, Bucharest (in Romanian)

75. Stefanescu, L., M. Dumitru (1991). Coditions for using urban sewage sludges, The Environment, vol. II, nr 1-2, 15-25 (in Romanian)

76. Stepanescu, E., I. Brant, I. Borza (1978-1980). Research on the pollution due to residues for industrial pig farms, Scientific reports of the National Institute for Agrochemistry and Soil Science (in Romanian)

77. Vadineanu, A. (1999). Decision making and decision support systems for balancing Socio-Economic and Natural Capital Development, Background paper at International Conference "Globalization, Economy and Ecology – Bridging worlds" 24 – 26 November 1999, Tillburg, Olanda, 24 pp, format CD-ROM

78. Vadineanu, A., S. Cristofor, V. Iordache (2001). Lower Danube River System biodiversity changes, In: B. Gopal, W. J. Junk and J. A. Davis (Eds), Biodiversity in Wetlands: Assessment, Function and Conservation, Backhuys Publishers, 29-63

79. Vadineanu, A., V. Iordache, A. Neagoe, S. Cristofor, C. Cociug, C. Postolache (2000). Research direction in landscape ecotoxicology, Mengen und Spuren Elemente, 20, 220-227

80. Varduca, A. (2002). Integrated monitoring of water quality – current state and perspectives,Annals of the scientific session "Environment and future" National Institute for Environmental Protection, Promotal Press, Bucharest, 21-28 (in Romanian)

81. Vijiiala, M., M. Dumitru, L. Stefanescu, E. Gament, V. Stan, G. Campeanu, A. Berendei, I. Gueran (1994a). Researches concerning the possible use of fermented city sludge, Scientific Annals of the University of Agriculture Bucharest, series A. vol. XXXVII, 99-107 (in Romanian)

82. Vijiiala, M., M. Dumitru, R. Ciofu, E. Dumitru, V. Stan, E. Gament (1994b). The influence of domestic fertilization upon the heavy metal content and crop yield,

Proceeding of the 24th annual meeting of ESNA (European Society for new methods in agricultural research, Working Group 5: environmental aspects and energy use, Ed. by E. Smedile and S. Grego, 60-71

83. Vincu, M., S. Sarafoleanu, D. Ilie, D. Plesca, Z. Garban (1998). Preliminary research concerning the distribution of metals in humans and food of animal origin, Procedings of the annual session for food technologies of the Agriculture University. Timisoara, vol. IV, "Agroprint" Press, Timisoara (in Romanian)

84. Vlad, M., E. Caseanu, P. J. Porr, G. Uza (2000). The concentration of Ca, Mg, Fe, Cu, Zn, Li, and Cr in some foods in Transilvania area, Proceedings of 4rd international symposium on "Metal elements in Environment, Medicine, and Biology", Timisoara, Romania, 317-322

85. Vrinceanu, N., M. Dumitru, A.-R. Voiculescu (1997). Aspects concerning the soil pollution with organic and inorganic compounds in Romania, retrieved august 2002 from www.ics.trieste.it/documents/chemistry/ remediation/publications/Soil1997 /.%5C20_Romania.pdf

Figures legends

Figure 1 Simplified homomorphic model used for computing the balance for the agricultural lands of Romania. Legend: 1 urban sewage sludge, 2 natural fertilizers, 3 N, P, K fertilizers, 4 atmospheric depositions, 5 irrigation, 6 animal wastes not used as fertilizers, 7 animal waste water, 8 main plant food products, 9 leaching, NE not evaluated.

Figure 2 Conceptual framework for a research program in landscape biogeochemistry, nutrition science and ecotoxicology. *Legend*: Black arrows = fluxes of elements, gray arrows = control pathways, squares = systems, circles = control parameters.

Figure 1

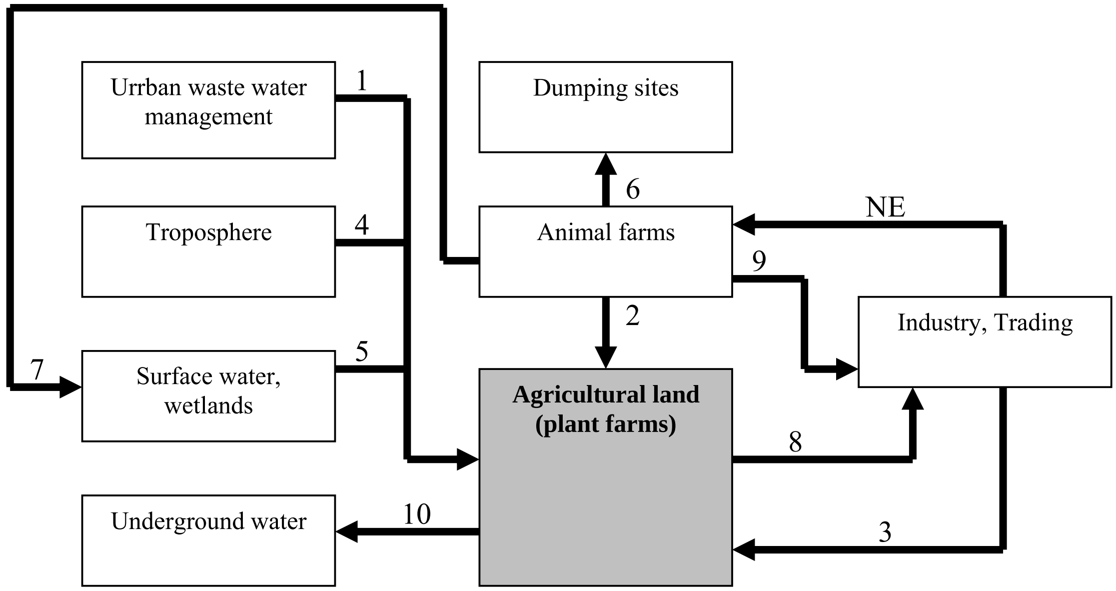
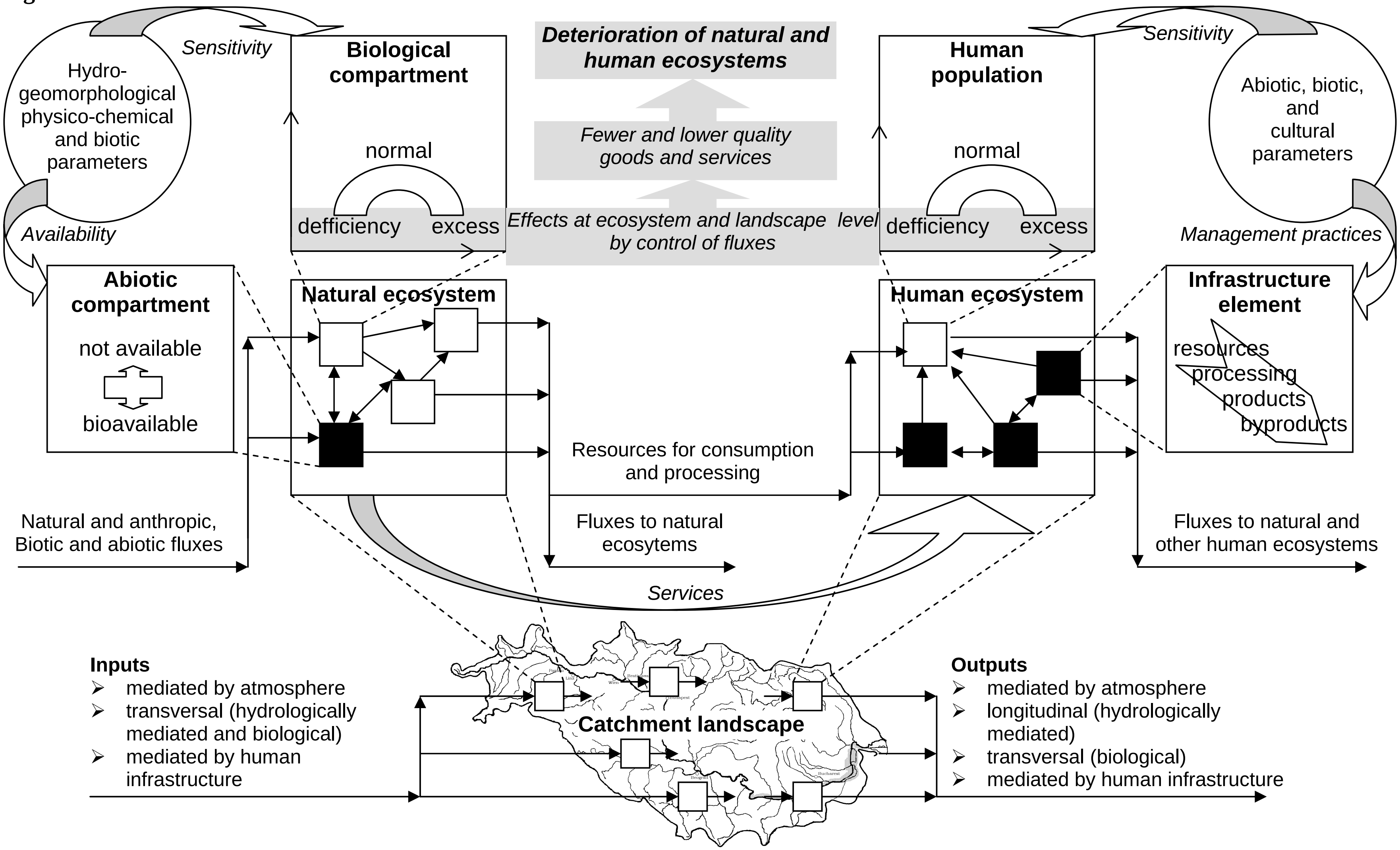

Urrban waste water management
Dumping sites
Troposphere
Animal farms
Industry, Trading
Surface water, wetlands
Agricultural land (plant farms)
Underground water
1
2
3
4
5
6
7
8
9
10
NE

Figure 2


Sensitivity
Biological compartment
Deterioration of natural and human ecosystems
Human population
Sensitivity
Hydro-geomorphological physico-chemical and biotic parameters
normal
Fewer and lower quality goods and services
normal
Abiotic, biotic, and cultural parameters
defficiency
excess
Effects at ecosystem and landscape level by control of fluxes
defficiency
excess
Availability
Management practices
Abiotic compartment
not available
bioavailable
Natural ecosystem
Human ecosystem
Infrastructure element
resources
processing
products
byproducts
Resources for consumption and processing
Natural and anthropic, Biotic and abiotic fluxes
Fluxes to natural ecosytems
Fluxes to natural and other human ecosystems
Services
Inputs
mediated by atmosphere
transversal (hydrologically mediated and biological)
mediated by human infrastructure
Catchment landscape
Outputs
mediated by atmosphere
longitudinal (hydrologically mediated)
transversal (biological)
mediated by human infrastructure

Table's caption

Table 1 Surfaces with productive capacity affected by limiting factors. In bold are typed the factors related to metals (adapted after Dumitru et al., 2001).

Table 1

Legend:

[1] One and the same surface can be affected by one ore more limiting factors

Table 2 Areas covered by excessively polluted agricultural land in 1992 (after Vrinceanu et al., 1997). In bold, sources related to agriculture.

Table 3 Contents (ppm d.w.) of potential polluting elements in top soil of monitoring sample plots by main agricultural land uses (A; surfaces in 2000 given in thousands of ha, n = number of sampling stations) and soil types (B). After Dumitru et al. (2000).

Table 4 Assessment of total animal wastes produced in 2000.

Table 5 Chemical parameters of animal manure, sludge and composts.

Table 6 Chemical parameters of industrial and urban sludge and composts (* = average for 3-5 consecutive years).

Table 7 Chemical parameters of animal farm waste water

Table 8 Estimated fluxes and balance for agricultural lands of Romania (g/ha agricultural area in year 2000), the land surface relevant for the considered fluxes, and a short characterization of the data used for computation.

Table 9 Priorities for future research activities in order to improve the knowledge concerning heavy metal balance in agricultural ecological systems.

Table 9

Legend:

[a] available knowledge: 1 = none, 2 = little, 3 = sufficient

[b] Kind of research/information needed: e.g. fundamental data, harmonisation, demonstration in practice, etc.

[c] relevance for balance outcome: 1 = low/not relevant, 2 = medium, 3 = high; ? = difficult to assess from the country's point of view

[d] research priority: 1 = none, 2 = little, 3 = medium, 4 = high, 5 = very high priority

Table 1

Factor	Affected surface[1] (thousands of ha)	
	total	of which arable land
Frequent drought	7100	
Periodic soil humidity excess	3781	
Soil erosion by water	6300	2100
Soil erosion by wind	378	
Landsliding	702	
Soil salinization	614	
Soil compaction	6500	6500
Topsoil hard layer	2300	2300
Low and very low humus pool	7485	4525
Moderate and high acidity	3424	1867
Low and very low burden of mobile P	6330	3401
Low and very low burden of mobile K	787	312
Low and burden of N	5110	3061
Deficiency in microelements (Zn)	**1500**	**1500**
Chemical pollution of soil, of which	**900**	
excessively polluted	**200**	
polluted with oil and salted water	50	
polluted by air dispersal	**147**	
Soil destruction by excavations	15	
Soil covering by solid wastes	18	

Table 2

Pollution causes	Area (ha, %)		Polluting economical branch
Emissions caused by compounds of heavy metals, nitrogen and sulfur oxides, dusts and gases	53179	31.422	chemical and petrochemical industry
Releases of oil, salty water and derrick sludge	49368	29.170	oil extraction industry
Emissions of gases and deposits of dusts with metal compounds	28251	16.693	metallurgical industry
Emissions in air of some calcareous dusts resulted from plants building materials and refractory materials	15516	9.168	building material industry
Emissions of supper and nitrogen oxides, release of ashes from spoil banks taken by wind	11806	6.976	thermo-energetic industry
Deficiencies in the activity of ore extraction processing	7453	4.404	mining industry
Industrial dusts, wastes and waste water	300	0.177	mechanical engineering industry
Dusts of ferric oxides	300	0.177	
Storage of industrial wastes	15	0.009	
Storage of ballast products	14	0.008	
Release and deposition of animal wastes from zootechnical farms	**1149**	**0.679**	**agriculture**
Waste waters, dirt and wastes	11	0.006	food industry
Storage of dirt, wastes and industry	1880	1.111	local administration

Table 3

A (range and average)

Element	Arable (9381.1 n=437)		Vineyards (272.3 n=18)		Orchards (254.6 n=16)		Pastures (3441.7 n=140)		Meadows (1507.1 n=59)	
	range	average	range	average	range	average	range	average	range	average
Cu	8-220	24	10-125	34	15-88	29	5-27	21	5-80	26
Pb	7-92	28	10-45	29	10-45	29	6-170	32	12-95	30
Zn	23-500	87	45-250	98	48-460	139	10-360	88	33-475	122
Cd	0 (udl)-2.5	0.9	0 (udl)-1.5	0.7	0.4-2	1	0 (udl)-5	1	0 (udl)-3	1.1
Co	3-35	18	5-25	17	6-35	18	2-25	17	5-40	19
Ni	7-85	34	15-60	33	13-55	37	5-75	32	10-105	35
Mn	120-1195	505	290-890	496	310-670	473	30-1193	458	125-1326	481
Cr	10-193	54	15-98	52	30-103	52	5-154	49	14-430	54
S soluble	22-1036	209	77-393	201	121-1036	301	14-2046	254	30-460	189

B (average)

	vertisols	molisols	argiluvisols	cambisols	undeveloped soils	spodosols	umbrisols	hydromorphic soils	halomorphic soils
Cu	26	24	22	24	25	19	20	25	20
Pb	29	27	29	32	31	35	25	34	11
Zn	127	96	82	101	97	57	157	101	76
Cd	1	0.9	0.8	1.1	0.9	0.8	1.7	1	1.8
Co	18.7	18	16	19	19	12	25	17	5.5
Ni	33	35	27	37	37	25	32	37	21
Mn	469	504	497	486	492	270	455	501	373
Cr	51	56	47	51	56	39	45	57	46
S soluble	245	206	204		265	247	131	231	381

Table 4

		No of animals in 2000 (thousands)	Waste water* l/animal/day	waste (urine and feces)		Total waste (t/year)		Total waste water (m3/year)**
				t wet/animal/year	t dry/animal/year	wet mass	dry mass	
Cattle	Cows	1769	30	14.94	1.89	2642886	334341	19370550
	Other	1282	30	6.7	0.77	858940	98714	14037900
Subtotal cattle		**3051**				**3501826**	**433055**	**33408450**
Pigs		5848	25	2.38	0.21	1391824	122808	53363000
Sheeps		7906	4	0.73	0.18	577138	142308	***
Goats		558						
Horses		858						
Poultry	For eggs	38497	0.08	3.86	0.96	14859842	3695712	1124112
	Other	30646	0.08	2.62	0.65	8029252	1991990	894863
Subtotal poultry		**69143**				**22889094**	**5687702**	**2018976**
GENERAL TOTAL						***28359882***	***6385873***	***88790426***
Source		***, 2001a	Jinga et al, 1990	Rauta and Dumitru, 1986	Rauta and Dumitru, 1986			

* technological changes may have changed the amounts currently produced

** where computed, we assumed that 100% of the animals are grew in animal farms, which is over estimation

*** not computed because percent of sheeps grew in industrial animal farms is presumably very far from 100%, due to traditional raising in the mountains

Table 5

		Solid manure					Animal sewage sludge					Animal sewage sludge compost		
parameter	**dimension**	sheep	poultry	poultry	cattle	cattle	pig	pig	pig	pig	poultry	pig	pig	pig
water content	% fm		39.8					66.8		82	69.01			
pH	-		5.3						7	6.23	8.04			
Cd-content	mg/kg dm	0.3	5.35	6.3	5.2	1.67		0.04	0.055		3.05	4.4	200	2.9
Cr-content	mg/kg dm	6.4	84.5	65	190			6.1	42.6		229.5	175	1133	54
Cu-content	mg/kg dm	7.7	254.5	100	40	20	7	39	81	7	97.5	138	602	213
Ni-content	mg/kg dm	4.3	7	3.8	2.7	14					14.65	4.7	117	3.7
Pb-content	mg/kg dm	4	90	30	28	29		5.7	5.7		69.5	51		20
Zn-content	mg/kg dm	230	414	390	250	101	42	113	101.35	42	1487	454	2103	497
N-total	% dm	0.98	0.92	2.15	1.44	1.84	3.4	2.42	3.015	3.4	0.755	0.88	1.72	1.67
P-total	% dm	0.57	0.745	1.7	0.7	0.52	1.09		0.57	1.09	1.48	0.61	1.43	
K-total	% dm	0.9	0.545	1.9	2.68		0.23		0.155	0.23	3.34	0.88	0.67	
Mg-total	% dm	0.72	0.64	0.69	0.58			0.29			1.455	0.3		0.41
Ca-total	% dm	0.72	1.83	0.77	0.57			1.17	1.065		3.35	0.65	1.03	1.39
C-total	% dm							30.6	25.72					
NO3-N-(CaCl2)-soluble	mg/100g dm	321		11	120.6			22.5	103	194	1.9	11.6		442
NH4-N-(CaCl2)-soluble	mg/100g dm	152	45.55	1.5	0.5			33.2		962	7.875	0.1		293
P-(lactate)-soluble	mg/100g dm													
K-(lactate)-soluble	mg/100g dm	2587	905	1000	660			3			260.5	42	5.75	
Mg-(CaCl2)-soluble	mg/100g dm	185	176.5	18.7	28.9			51			102	28.9		
soluble SO4-S	mg/100g dm	3136	6223.5		946.4			113			1475	210.9		
B	mg/kg dm													13
Mn	mg/kg dm	681	1270	740	430	267		312			492.5	822	390	757
Fe	mg/kg dm	1396	9200	2030	6290				524.5		13359	16900	24460	17960
Na	mg/kg dm		2650					672	1500	780	11000			
Cl	mg/kg dm	1335		1636	1087			125			968.5	81		
Co	mg/kg dm	1.9	19	8.8	8.2	8		2.7	0.73		6.575	14		29
Ca++	mg/kg dm	190	950	900	210			510			205	688	159	
Data source		Dumitru et al., 1990	Dumitru et al., 1989c	Dumitru et al., 1989c	Dumitru et al., 1989c	***, 1981-87	Dumitru, 1983	Dumitru et al, 1993c	Dumitru et al., 1986	Nastea et al., 1986a	Dumitru et al., 1989c	Dumitru et al., 1989c	***, 1981-87	***, 1988, nr 7

Table 6

		Industrial sewage sludge				Urban sewage sludge					Urban sewage sludge compost		Urban household wastes compost		
parameter	**dimension**	celulose industry	celulose industry	leather industry	chemical industry	Bucharest	Bucharest*	Cluj-Napoca	Bucharest	Timisoara*	Bucharest	Bucharest*	Bucharest*	Bucharest	Bucharest
water content	% fm				75.6		53.75		57.43	49.3		38.85			
pH	-				8.42		7.5		7.17	5.8			8.28	8.3	8.45
Cd-content	mg/kg dm			13	4	68	38	32.5	48	23	200	23.9	12.5	13	12
Cr-content	mg/kg dm			3916	9	3485	505	2567	760	982	1135	833.75	189	224	150
Cu-content	mg/kg dm	139.93	224	310	242	841	473	352	558	509	602	3919.5	168	129	173
Ni-content	mg/kg dm			5.1	22	18.8	102	103	21		117	69	45	47	35
Pb-content	mg/kg dm	114	217.5	202	119	300	238	801	375	261	410	231	394	365	320
Zn-content	mg/kg dm	286.67	227.33	1692	497	3910	2025	1145	3240	619	2103	1894	1285	250	1780
N-total	% dm	2.18	2.76	0.98	8.23	0.51	0.72	3	0.53	0.97	1.72	0.615	1.57	1.67	1.35
P-total	% dm	0.99	0.93	0.116	1.5	0.82	0.66	1.1	1.16	0.58	1.43	2.155	0.29	0.36	0.21
K-total	% dm	1.5	1.21	0.035	1.8	0.96	0.91	0.7	1.4	1.42	0.07	5	1.03	1.5	0.53
Mg-total	% dm			0.071	2.01	0.48	0.77		0.97	0.3	0.43	1.375	0.28	0.39	0.16
Ca-total	% dm	0.2	0.48	1.9	15.2		0.66		0.65	0.35	1.03		2.18	2.95	1.35
C-total	% dm						11.56		24.53	36		47.35		37.4	
NO3-N-(CaCl2)-soluble	mg/100g dm			35,7		0.875	8		9		1.65	43.2	8.9	12.8	5.2
NH4-N-(CaCl2)-soluble	mg/100g dm					2.431	14.7		22.2		11.4	27.585	31.3	0.1	71.9
P-(lactate)-soluble	mg/100g dm	5.464	2.804				22.3					18.4			
K-(lactate)-soluble	mg/100g dm	7.576	40.716	2.6	5.25	15.5	44		5.32		5.75	9.36	351.2	440	281
Mg-(CaCl2)-soluble	mg/100g dm			9.93		16.5	9.3		1.3		0.015	7.45	209	23	18.7
soluble SO4-S	mg/100g dm	1311.3	1964.83	769.7		936.1	2062.3		4492.2			2415.85	748.5	845.2	677
Mn	mg/kg dm	51.67	203.83	258	212	605	492	536	630	214	350	468.9	523	400	680
Fe	mg/kg dm	4233.33	5586.33	25818	5520	25155	24843	20790	24167		24460	22638.5			
Na	mg/kg dm				9700		3600		2100			14150	8000	12500	5300
Cl	mg/kg dm			856.1		80.65						1790.15	5370	6581	4309
Co	mg/kg dm	2.78	12.16	8.9	9	31.5	24	29.01	28	25	16	24.5	12	12	11
Ca++	mg/kg dm			1197		125			1260		159	2300	1288	1500	1025
Data source		***, 1981-87	***, 1981-87	***, 1981-87	Dumitru et al., 1984	***, 1981-87	Dumitru et al., 1993b	Blaga et al., 1989	Dumitru et al., 1994	Borza and Radulescu, 2000	***, 1981-87	Vijiiala et al., 1994a	Vijiiala et al., 1994b	Dumitru et al., 1991	Dumitru et al., 1993a

Table 7

parameter	dimension	cattle	pig	pig	pig	pig	pig	poultry	poultry
pH	-		8.42	7.5	7.78				
Cd-content	mg/l	0.07	0.016		0.02		0.027	0.01	0.11
Cr-content	mg/l	0.06	0.072		0.059		0.067	0.16	0.24
Cu-content	mg/l	0.5	0.01		0.04		0.1	0.15	0.08
Ni-content	mg/l	1.1	0.037		0.018		0.26	0.015	0.014
Pb-content	mg/l	0.4	0.087		0.239		0.434	0.09	0.36
Zn-content	mg/l	1.1	0.48		0.74		0.96	1.34	1.26
N-total	mg/l	468	250	430	323	430	521	196	207
P-total	mg/l	226	36.08	71	47	60	56	8.82	26.6
K-total	mg/l	1625	201	231	224	220	220	56	109
Mg-total	mg/l	1623	38.9		50		71	43.17	0.04
Ca-total	mg/l	596	89		104		108	106	110
NO3-N	mg/l			0.56	3.72		6.2	2	11.5
NH4-N	mg/l	320	52.45	178.2	567		618.3	23.54	10
K+	mg/l	28.6		120	216.45	129.5	242.58	60.5	90
Mg++	mg/l	6.4		51	51.96	59	67.92	42	33
SO4-S	mg/l	3.6		580	94.8	550	114.4	308.17	0
Mn	mg/l	1.2	0.025		0.12		0.028	0.76	0.63
Fe	mg/l	1.4	4.3		5.51		5.74	8.31	7.07
Na	mg/l		105	280	104				
Cl-	mg/l	23.4		425	182.87		219	198.67	663
Co	mg/l	0.2	0.055		0.049		0.044	0.003	0.05
Ca++	mg/l	11.2		29	68	30	70.4	77.83	125
Data source		Dumitru et al., 1989d	Nastea et al., 1986b	Nastea et al., 1986a	Dumitru, 1991	Rauta et al., 1980	Dumitru et al., 1989a	Dumitru et al., 1989c	Dumitru et al., 1989c

Balance for Romania: review

Table 8

Inputs (as over 14856800 ha)	Cu	Zn	Co	Ni	Mn	Cd	Pb	Cr	Real surface of input / output (ha)	Source of data: concentrations, amount or fluxes
Urban sewage sludge	0.596	2.386	0.030	0.067	0.540	0.046	0.431	1.810	15000	conc and amount (average Ro literature)
Natural fertilizers	69.576	337.432	7.438	8.240	637.461	2.922	34.844	94.893	647200	conc and amount (average Ro literature)
N fertilizers	0.053	0.157	NE	0.360	0.032	0.064	0.122	0.045	3724578	conc (average European literature), amount (Ro literature)
P fertilizers	0.134	1.450	0.012	0.321	0.594	0.099	0.122	0.933	3724578	conc (average European literature), amount (Ro literature)
K fertilizers	0.002	0.006	NE	0.016	0.018	0.003	0.010	0.002	3724578	conc (average European literature), amount (Ro literature)
Atmospheric deposition	2	100	1.4	7.5	17.5	2.5	40	NE	14856800	fluxes (half of the average for Hungary)
Irrigation	0.825	4.123	NE	2.062	NE	0.041	0.206	2.062	204200	conc (Ro regulations, water class 2), amount (as described in the report)
Total input	***73.185***	***445.553***	***8.880***	***18.565***	***656.145***	***5.675***	***75.734***	***99.744***		
Outputs (as from 14856800 ha)										
Animal wastes	55.208	267.751	5.902	6.538	505.823	2.319	27.648	75.297	14329900	conc (Ro literature) amount (estimation based on Ro literature)
Animal waste water	0.877	5.857	0.399	1.438	2.752	0.252	1.604	0.655	14329900	conc (Ro literature) amount (estimation based on Ro literature)
Main plant food products	20.706	138.040	1.380	1.063	6.902	1.380	13.804	0.690	14856800	conc and amount (regulations and Ro literature)
Main animal food products	0.389	6.476	NE	NE	NE	0.013	0.065	NE	14329900	conc and amount (regulations and Ro literature)
Leaching	<1	<1	<1	<1	<1	<1	<1	<1	NE	fluxes (Ro literature as described in the report)
Total output	***77.179***	***418.124***	***7.682***	***9.039***	***515.477***	***3.964***	***43.121***	***76.643***		
Balance	**-3.994**	**27.430**	**1.198**	**9.526**	**140.668**	**1.711**	**32.613**	**23.101**		

Table 9

Research field	Knowledge/ data available (1 - 3) [a]	What is needed? -- [b]	Relevance for balance (1 – 3; ?) [c]	Research priority (1 – 5) [d]	comments
Fundamental research					
analysis, methodology	2	improvement and harmonisaton of existing knowledge	2	3	focused by now on N and P balances in fluvial systems and in agricultural landscapes
soil research	3	GIS development	2	3	running research initiatives
Heavy metal inputs					
material research	2	fundamental data	?	2	
animal nutrition	2	fundamental data	1	4	by now only in terms of needed micronutients, not in terms of pollution with heavy metals
animal medication	1	fundamental data	1	2	
mineral fertilisers	2	fundamental data	3	3	
atmospheric deposition in rural areas	2	improvement of the monitoring	2	5	by now only related to the pan-European monitoring of forest ecosystems
special crops	3	GIS development	3	4	
inputs special for organic farming	2	fundamental data	2	2	before 1989 pilot studies in experimental fields
Heavy metal outputs					
leaching	1	fundamental data	2	4	
erosion/surface run off	2	fundamental data	3	5	known only the surfaces affected by erosion in different degrees, but no quantification of fluxes
soil-plant-transfer/food chain	3	GIS organization	3	3	running research initiatives
removal of soil with crops	1	fundamental data	2	2	
Balancing					
mass flow determination	2	fundamental data	3	5	limited to experimental fields
models for unknown fluxes	1	models development	3	4	most needed would be GIS models of atmospheric deposition and erosion
balancing approaches	2	studies for metals in agricultural landscapes	3	5	done for metals in the Danube floodplain, and for N & P in the Danube floodplain and in agricultural catchments
Monitoring					
organic farming	2	design of monitoring	2	3	organic farming still in development
farm level monitoring	1	design of monitoring	3	5	
livestock feeds	1	design of monitoring	3	4	
animal manure, industrial and bio-waste	2	improvement of monitoring	3	4	existing in terms of general quantities, but lacking in terms of subtypes and contamination with metals