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Review

Heavy metals balance in Polish and Dutch agronomy: Actual state and previsions for the future☆

Jacek Dach[a,*], Dick Starmans[b]

[a] Institute of Agricultural Engineering, Agricultural University of Poznan, Wojska Polskiego 50, PL-60-627 Poznan, Poland
[b] Agrotechnology and Food Innovations, Wageningen University and Research Centre, Bornsesteeg 59, P.O. Box 17, 6700 AA Wageningen, The Netherlands

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Abstract

This paper presents the state of agro-ecosystem contamination with heavy metals in relation to the level of agricultural development. For this, the Polish and Dutch agricultural situations were compared. The intensive animal and vegetable production observed in the Netherlands over the past 20–30 years was found to substantially contribute to the heavy metal input of these systems. Agriculture in Poland is on the brink of a rapid economical and technological push promoted by the recent admission of Poland to the EU. The current low levels of organic fertilization in this country are expected to increase dramatically in the next few years, leading to an increased environmental burden of heavy metals, similar to that observed in the Netherlands. Awareness of the danger of heavy metals to public health is slowly taking hold, as the EU takes up its responsibility regarding the maximum limits of some of these compounds allowed in mineral fertilizers. However, the authors would like to stress that the major contribution of heavy metals arises from the use of organic fertilizers. Proper dealing with this through means of adaptation of feed regimes and/or remediation could both safeguard the yet unpolluted soils in Poland and prove essential to halt the ongoing pollution of soils in the Netherlands.

Keywords: Heavy metals; Agro-ecosystems; Fertilization; Manure; Intensive agronomy; Environmental protection

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* Corresponding author. Tel.: +31 317 746592; fax: +31 317 475347.
E-mail address: jdach@au.poznan.pl (J. Dach).

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1. Introduction

The task of modern day agriculture is to safeguard the production of high quality food, in a sustainable natural environment under the precondition of pollution not exceeding accepted norms, and productive technologies not degrading the environment. However, the strong intensification of plant and animal production observed in Western Europe during last 30–40 years resulted in huge changes of the landscape and the disruption of well-balanced agro-ecosystems (Stoate et al., 2001). Moreover, it lead to strong environmental pollution and contamination of agricultural products (Wiersma et al., 1986) with increased levels of heavy metals that could endanger consumers (van de Voet et al., 1999; Nasreddine and Parent-Massin, 2002; Brus and Jansen, 2004; Hough et al., 2004).

As a consequence, consumer awareness triggered the transformation of EU food policy into a proactive, dynamic, coherent and comprehensive instrument to ensure a high level of human health and consumer protection (CEC, 2000). The new EU farm to table policy specifically addresses farmers as the link in the food chain having the primary responsibility for food safety.

With its high level of agricultural intensity, the Netherlands are in the lead regarding the problems related with heavy metals and corresponding dangers to public health (Moolenaar and Lexmond, 1999). The current situation in Poland is still much healthier due to the low intensity of Polish agriculture (IOS, 2003). However, the latter situation is changing rapidly with Poland becoming an EU member state (MRiRW and ARiMR, 2003).

It was found in literature (Kabata-Pendias and Pendias, 1999; Dach and Jakubus, 2001; IOS, 2003) that 5 of the 6 most commonly found heavy metals in Polish national ecosystems were introduced as a result of the use of animal manure rather than being introduced by the use of artificial fertilizers. With the change in Polish agriculture, a shift will occur from solid to liquid manure. Also the total amount of manure produced is expected to increase as a result of modernization and intensification with EU funding. Therefore, it is also to be expected that the area of land used for spreading animal manure in the near future will exceed the area dedicated to environmentally friendly organic fertilizing. In other words: the problem of heavy metals in consumer products will expand throughout the entire Polish agriculture sector, similar to the situation in the Netherlands.

From literature (Moolenaar and Lexmond, 1998; de Vries et al., 2002) it is known that the significant decrease of soil quality in view of heavy metals by irresponsible agricultural policy can occur during a few years but the natural purification of the soils will be attained after hundreds of years. This means that it is very important to limit heavy metal flux from using fertilizers during the next years. Although the problem with heavy metals is present for all agricultural activity, it is most pertinent in ecological farming. Because the heavy metal content of organic fertilizers exceeds that of artificial fertilizer by far, these farms apply more heavy metals to the land as compared to farms with regular mixed farming systems (Keller and Schulin, 2003) where organic fertilizer is partly replaced by artificial fertilizer. Specific problems arise with copper and lead when farming totally relies on the application of organic fertilizer. Scientists (Moolenaar and Lexmond, 1998; Keller and Schulin, 2003) have found this phenomenon during the research in farm case studies where the input and output of soil contamination by heavy metals was calculated.

The increase of arable land used by ecological farms in EU countries has increased substantially from 200,000 ha in 1986 to the amount of 3.8 mln ha in the year 2000 (UKIE, 2003). This renders the entire EU more vulnerable to these problems.

The purpose of this paper is to make an assessment of the heavy metal content in Polish and Dutch agricultural systems including an estimation of the annual input by fertilization. Additionally, a brief overview is presented on possible future scenarios with regard to the development of the heavy metal balance in agronomy.

2. Material studied

To study the effect of agricultural intensity on the heavy metal input to the environment, two EU countries with different levels of agricultural intensity were compared in this paper. The Netherlands were taken as an example of a country with intensive agriculture production and high doses of fertilizers used and Poland as an example of the country with a low level of intensity in agriculture. The data used were collected from national Dutch and Polish Central Statistic Offices (CBS and GUS) and analysis of heavy metal content in different mediums made in national and international researches. Apart from the degree of contamination of agro-ecosystems with heavy metals as a consequence of the fertilization and feeding an outlook is given into future developments in this field.

3. Heavy metal balances at a national scale

The short comparison of Polish and Dutch agronomy given in Table 1 clearly shows the differences in the level of intensity of agricultural production between these countries.

Although the Polish agricultural area is more than 9 times bigger, the size of total animal production is comparable (only 27% more of pigs, 32% more cattle and about half the amount of chicken). The data on the amount of animals per total agricultural surface, the doses of mineral fertilization and the production of manure clearly shows the huge difference in the level of intensification between Polish and Dutch agronomy.

3.1. Situation in Poland

The official criteria of heavy metal pollution used to assess the soil quality in Poland was developed by the Institute of Soil Science in Pulawy. Six levels of contamination are distinguished (Table 2), of witch the first two categories (natural concentrations and slightly increased concentrations) are perceived as safe for human health and environment.

At present (2003), the quality the soil used in Polish agriculture is very good in terms of heavy metal concentrations because about 97% is classified as natural or slightly increased (0 and *i*th indices of pollution) (IOS, 2003). The input of heavy metals by using fertilizers in Polish agricultural farming is still lower than that of the West because of lower doses (in kg ha^{-1} year^{-1}: 48.4 N; 17.3 P_2O_5; 19.8 K_2O and 104.2 CaO for mineral fertilizer only) (GUS, 2000).

It was found in literature (Kabata-Pendias and Pendias, 1999) that mineral fertilizers are a significant source of heavy metals in the top layer of soils (Table 3). In this regard it should be noted that due to the regression in Polish agriculture during the 1990s, the applied dose of mineral fertilizer decreased substantially for a prolonged period of time (Fig. 1).

Table 1
Characteristic of Dutch and Polish agronomy

Specification		The Netherlands	Poland
Land use agricultural area, 2002	1000 ha	1,949	18,345
Land use arable land, 2002	1000 ha	916	13,922
Average annual mineral fertilizer use, 1999	kg ha^{-1}	501	106
Production of total manure (solid and liquid), 2002	10^6 t	70.8	173.3
Average crop yield of cereals, 1999	kg ha^{-1}	7,701	2,861
Percent of cropland that is irrigated, 1999	%	59.5	0.7
Agricultural workers as a percentage of the total labour force	%	4.6	27.5
Pigs stocks, 2003	Head	13,567,000	18,537,604
Cattle stocks (head), 2003	Head	3,780,000	5,488,943
Chicken stocks, 2003	Head	98,000,000	48,393,000

Source: van Noort and van Egmond (2001), GUS (2003), van Bruggen and Heijstraten (2003), FAOSTAT (2004).

Table 2
Indices of pollution (mg kg^{-1}) of surface layers of soils with heavy metals in Poland

Metal	Soil	0	I	II–V
Cadmium (Cd)[a]	L	0.3	1.0	≥2
	M	0.5	1.5	≥3
	H	1.0	3.0	≥5
Copper (Cu)	L	10	30	≥50
	M	20	50	≥80
	H	25	70	≥100
Chromium (Cr)	L	20	40	≥80
	M	30	60	≥150
	H	50	80	≥200
Nickel (Ni)	L	10	30	≥50
	M	25	50	≥75
	H	50	75	≥100
Lead (Pb)	L	20	70	≥100
	M	40	100	≥250
	H	60	150	≥500
Zinc (Zn)	L	50	100	≥200
	M	70	150	≥300
	H	100	250	≥500

Adapted from IOS (2003).
[a] L, light soil; M, medium-heavy soil; H, heavy soil.

Table 3
Estimated average heavy metal input (g ha^{-1} year^{-1}) by animal manure and mineral fertilizer in Poland

Fertilizer	Cd	Cr	Cu	Ni	Pb	Zn
Total mineral fertilizers (NPKCa)	1.05	19.00	4.11	5.40	5.49	28.26
Total manure	0.38	20.82	21.44	13.07	7.47	91.64

Source: Dach and Jakubus (2001).

The agricultural income per ha of Polish farmers in 1999 decreased to 31% of the level of 1990 (Guba, 2002).

The Polish annual heavy metal input into the environment via animal manure is not high (Table 3) when comparing to the Dutch flux, because of the relatively low average dose of fertilizer used (0.69 t dm ha^{-1} yearly) (GUS, 2000). However, the heavy metal input by organic fertilizers is much higher than for mineral fertilizers. During the past years in Poland, production of farmyard manure dominated the amount of produced slurry. Although the fertilizing value of the farmyard manure (FYM) still surpasses that of the liquid manure (58.4% of total manure fertilization from farmyard manure), the total amount of liquid manure produced already surpasses that of FYM (GUS, 2003). With this development, problems related to heavy metal contamination of soils fertilized by organic manure might become similar to those observed in Western agriculture.

3.2. Situation in the Netherlands

The high development of Dutch agronomy influenced strongly the excess input of heavy metals (specifically cadmium, copper and zinc) in soils (Moolenaar and Lexmond, 1998). The net flux of heavy metals to the soil remains still positive (Table 4) although its value has decreased when comparing to the beginning of the eighties.

The data presented in Table 4 clearly show the very important contribution of animal manure to the net surplus load of Cu and Zn on arable land. It was found in literature (de Vries et al., 2002) that on farm level, feed concentrates contribute to most of the input of Cu and Zn. Depending on their origin, feedstuffs contain about 5–10 mg/kg Cu and 30–40 mg/kg Zn. In the preparation of feed for pigs, heavy metals are added to improve animal performance (Table 5). Although EU legislation on the amounts Cu and Zn sets out maximum values of 175 and 250 mg kg^{-1} feed respectively, recommendations from different scientific organizations showed that no extra additions of

Table 4
Input and output of heavy metals for arable land in the Netherlands

Metal	(10^3 kg) (values for *1980* and **2003**)											
	Total input		By animal manure		By mineral fertilizers		By deposition		Other sources		Total output	
Copper (Cu)	*1360*	**495**	*1050*	**425**	*150*	**35**	*80*	**20**	*80*	**15**	*140*	**95**
Zinc (Zn)	*2400*	**1520**	*1800*	**1250**	*150*	**50**	*280*	**80**	*190*	**140**	*700*	**560**
Cadmium (Cd)	*16*	**5**	*6*	**3**	*3*	**1**	*2*	**1**	*7*	**0**	*3*	**3**

Source: CBS (2004).

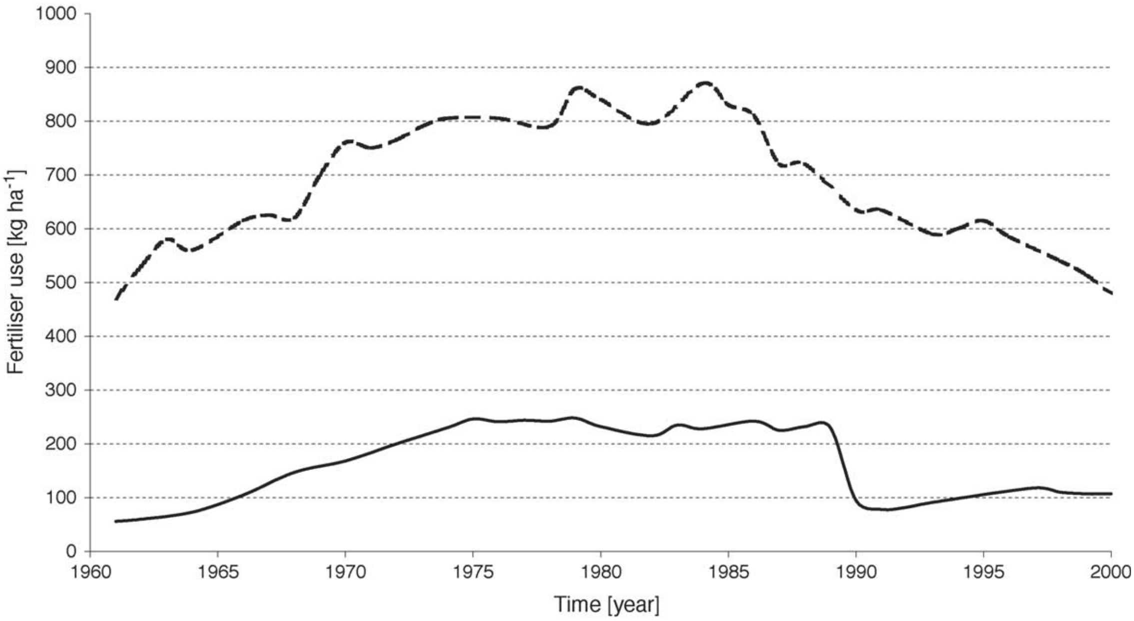

Fig. 1. Mineral fertilizer consumption per hectare of cropland in the Netherlands and Poland, adapted from EarthTrends (2003a,b).

Table 5
Maximum values[a] of heavy metals in feedstuffs for pigs in the Netherlands

Animal category	Cu (mg kg^{-1})	Zn (mg kg^{-1})
Piglets	170	135
Fatteners		
Starters (<16 weeks)	140	105
Finishers	25	95
Sows	30	100

Source: Melse (2000).
[a] As agreed by Dutch producers of animal feed on July 1st, 2000.

heavy metals to the animal feed are needed to cover the animal requirements (European-Commission, 2003a,b). Since no EU limits are set for the content of heavy metals in animal manures, decrease of the EU-allowed maximum values in animal feed should become the most important driver to limit the environmental pollution by agriculture.

Table 6
Average inputs (g ha^{-1} year^{-1}) of Cd, Cu and Zn to Dutch agricultural area

Fertilizer	Cu	Zn	Cd
Total mineral fertilizers (NPKCa)	17.96	25.66	0.51
Total manure	218.06	641.35	1.54

Adapted from CBS (2004).

Moreover, research (Melse, 2000) has shown that only a small portion of the heavy metals are retained by the animals. About 90% of the Cu and Zn is excreted into manure (Table 6). As a consequence, the average heavy metal content in Dutch manure is 7–10 times higher than the average content in manure from Polish farms where a large part of the feed is produced on the farm itself.

The main source of soil contamination by Cd is the use of mineral fertilizers, whereas atmospheric deposition is the main source of Pb (Groot et al., 1998; de Vries et al., 2002). Input into soils via animal manure is expected to be higher than other ways like mineral fertilizing, the use of pesticides or atmospheric deposition (Moolenaar and Lexmond, 1999). These heavy metals also can accumulate in soil and crops, and thus pose a serious threat to the environment and consumer health (Chambers et al., 1998). Comparison of Tables 3 and 6 also shows that the awareness of the danger of heavy metals is underexposed in the Netherlands, since no data with enough statistical background was available for Cr, Pb and Ni.

4. Discussion

During the 1980s, atmospheric deposition was one of the main sources of soil input of heavy metals in Poland. After 1990, the Polish industry was restructured and production facilities were modernised. The use of modern production equipment in the steel, petrochemical and chemical industry branches resulted in a decrease of anthropogenic pressure on the environment. Nowadays this place is taken by farmers using fertilizers, especially when using organic waste. The most common manure produced in Poland during the 1990s was solid farmyard manure (Romaniuk, 1995) but this is shifting towards the production of liquid manure upon integration of Poland in the EU and introduction of Western technology, i.e. through the European economic support (SAPARD and other sources). Following this change, the usage of feed concentrates is bound to go up as well, leading to an increase in the total manure and heavy metal load of the environment.

For the Dutch agronomy the flux of heavy metals by fertilizing is very high and connected with a high content of heavy metals in food concentrate (Moolenaar and Lexmond, 1998). Comparing the situations for the years 1980 and 2000, the annual total net load of copper decreased from 0.6 to 0.35 Cu kg ha^{-1} (but it is still more than 10 times higher than that for Poland); for cadmium there was a drop from approximately 6 to 1.5 g ha^{-1} (van Noort and van Egmond, 2001). Total net load of zinc remained nearly the same (nearly 1 kg ha^{-1} per year). These developments are caused by regulations limiting the amounts of heavy metals allowed in livestock feeds and by producing less contaminated feed stuffs. The situation for the Netherlands is alarming because of the high content of heavy metals in soils. Present metal inputs cause metal accumulation and metal leaching during a time period of several hundreds or even thousands of years (de Vries et al., 2002). For example, the natural re-equilibration of Cd and Zn is only reached after 100–1000 years, whereas it can take up to 3000 years for Pb and even 4000 years for Cu.

In view of this problem it is necessary to improve the quality of animal waste to ensure a responsible agricultural use. In the last years, the Netherlands (like many other countries in the West) have developed many different remediation technologies to remove heavy metals from soils (like, e.g. bioremediation, physical separation and electro remediation). However—removing heavy metals from the soil without diminishing the constant flux by fertilization is like carrying water to the sea. It is very important to decrease the heavy metal content in manure by reducing the in-flux through animal feed. This was recognized by the Dutch branch organization of animal feed stuff. Still, it remains impossible to remove the heavy metals from the feed completely, which means it can be very interesting and useful to introduce new technologies for the purification of liquid manure (like, e.g. electro remediation).

Contrary to the Netherlands, the current Polish situation concerning heavy metal pollution in agro-ecosystems is good. This is a result of the decreased pollution by heavy industry after 1990 and the permanent economic crises of Polish farms during the 1990s. However, this situation is changing with the entrance of Poland to the UE. From 2005 Poland will be the 3rd beneficiary of the EU budget (more than 7 milliard euro per year) and Polish agronomy will be the first beneficiary of this aid with huge European and national subventions (10,175 million euros for the period 2004–2006) (MRiRW and ARiMR, 2003). Official reports on the simulation of scenarios of the development of the Polish agronomy predict an immediate growth of farm income of at least 25–80%, depending on the size and kind of production (FDPA, 2001). A significant growth of plant and animal production is predicted for farms that grow cereals, pig farms and poultry farms (Burnat et al., 2001).

If the intensification of agricultural production in Poland becomes a fact in the near future, the higher level of fertilization, usage of pesticides and concentrated animal feed may cause similar pollution of the Polish environment as is the case in Western Europe.

With both Poland and the Netherlands facing problems related to the input of heavy metals by agriculture, it is clear that action is necessary. As suggested previously, the most logical thing to do would be to sharply reduce the input through animal feed. Other possible actions remain end-of-pipe solutions such as remediation.

5. Conclusions

- The comparison between Polish and Dutch heavy metal balances and fluxes clearly indicates that the development of intensive agronomy strongly influences the degree of pollution of agro-ecosystems. This pollution can create serious health problems and could prove a burden to future generations.
- The main source of heavy metal input into Dutch and Polish agro-ecosystems comes from the use of organic fertilizers. The high content of metal pollutants in manure is caused by a huge content of some metals in animal feed.
- The possibilities of reducing heavy metal fluxes have to be found in decreasing fertilizer doses, their purification (with using a new technology like, e.g. electro remediation) and the decrease of the heavy metal content in feed concentrates.
- The intensification of the Polish agronomy that is a result of the Polish entry to the EU can lead to an increase in soil pollution caused by the increased flux of heavy metals due to high levels of soil fertilization. To avoid this danger from happening, the utilisation of Western Europe experiences is very important.

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Reference

Brus, D.J., Jansen, M.J.W., 2004. Heavy metals in the environment. Uncertainty and sensitivity analysis of spatial predictions of heavy metals wheat. J. Environ. Qual. 33, 882–890.

Burnat, M., Ciechanski, J.S., Dolinska, X., Dzeciolowski, J., Grochowska, R., Kulesza, M., Lublinska-Kasprzak, B., Piskorz, W., Pitera, R., Wijaszka, T., Zwolinska, M., 2001. Rolnictwo. Kancelaria Prezesa Rady Ministrow, Warszawa (in Polish).

CBS, 2004. Zware metalen op landbouwgrond. Centraal Bureau voor de Statistiek, Voorburg, URL: http://www.cbs.nl/ (in Dutch).

CEC, 2000. White paper on food safety. Report no. 719. Commission of the European Community, Brussels.

Chambers, B.J., Nicholson, F.A., Soloman, D.R., Unwin, R.J., 1998. Heavy metal loadings from animal manures to agricultural land in England and Wales. In: Ramiran 98, Eighth International Conference on Management Strategies for Organic Waste Use in Agriculture, Cemagref Editions, Rennes, pp. 475–483.

Dach, J., Jakubus, M., 2001. National report from Poland. In: Eckel, H., Dohler, H., Roth, U. (Eds.), Assessment and Reduction of Heavy Metal Input into Agro-Ecosystems (AROMIS). EU Concerted Action QLK5-2000-00670. Kuratorium fur Technik und Bauwesen in der Landwirtschaft, Darmstadt, pp. 177–187.

de Vries, W., Römkens, P.F.A.M., van Leeuwen, T., van Bronswijk, J.J.B., 2002. Heavy metals. In: Haygarth, P.M., Jarvis, S.C. (Eds.), Agriculture, Hydrology and Water Quality. CAB International Publishing, Oxon, pp. 107–132.

EarthTrends, 2003. Agriculture and Food. Netherlands. World Resources Institute, URL: http://www.earthtrends.wri.org/pdf_library/country_profiles/Agr_cou_528.pdf.

EarthTrends, 2003. Agriculture and Food. Poland. World Resources Institute, URL: http://www.earthtrends.wri.org/pdf_library/country_profiles/Agr_cou_616.pdf.

European-Commission, 2003. Opinion of the scientific committee for animal nutrition on the use of copper in feedingstuffs. Health & Consumer Protection Directorate-General Directorate C – Scientific Opinions C2 – Management of Scientific Committees; Scientific Co-Operation and Networks, URL: http://europa.eu.int/comm/food/fs/sc/scan/out115_en.pdf.

European-Commission, 2003. Opinion of the scientific committee for animal nutrition on the use of zinc in feedingstuffs. Health & Consumer Protection Directorate-General Directorate C – Scientific Opinions C2 – Management of Scientific Committees; Scientific Co-Operation and Networks, URL: http://europa.eu.int/comm/food/fs/sc/scan/out120_en.pdf.

FAOSTAT, 2004. Agricultural data. Food and Agriculture Organization of the United Nations, URL: http://www.faostat.fao.org/abcdq/about.htmx.

FDPA, 2001. Gospodarstwa rolne w Unii Europejskiej. Koszty i korzysci. Fundacja na Rzecz Rozwoju Polskiego Rolnictwa, Warszawa (in Polish).

Groot, M.S.M., Bronswijk, J.J.B., Willems, W.J., de Haan, T., del Castilho, P., 1998. National soil quality monitoring network: results of 1995 (Landelijk Meetnet Bodemkwaliteit. Resultaten 1995). Report no. 714801024. RIVM (National Institute for Public Health and the Environment), Bilthoven.

Guba, W., 2002. Agricultural situation in the candidate countries. Country report on Poland. European commission Directorate-General for agriculture, URL: http://www.europa.eu.int/comm/agriculture/external/enlarge/publi/countryrep/hungary.pdf.

GUS, 2000. Statistical Yearbook of the Republic of Poland. Wyd. GUS, Warszawa (in Polish).

GUS, 2003. Srodki produkcji w rolnictwie w 2002 r. Statistical Information Centre, URL: http://www.stat.gov.pl/serwis/nieregularne/srod_prod_rol_2002.htm (in Polish).

Hough, R.L., Breward, N., Young, S.D., Crout, N.M.J., Tye, A.M., Moir, A.M., Thornton, I., 2004. Assessing potential risk of heavy metal exposure from consumption of home-produced vegetables by urban populations. Environ. Health Perspect. 112, 215–221.

IOS, 2003. The state of environment in Poland 1996–2001. Inspection for Environmental Protection, Warsaw.

Kabata-Pendias, A., Pendias, H., 1999. Biogeochemia pierwiastkow sladowych. Wyd. Naukowe PWN Warszawa, p. 364 (in Polish).

Keller, A., Schulin, R., 2003. Modelling heavy metal and phosphorus balances for farming systems. Nutr. Cycl. Agroecosyst. 66, 271–284.

Melse, R.W., 2000. Zware metalen en mestverwerking. 1. berekening van gehalten in mest(producten). Praktijkonderzoek Varkenshouderij 14, 9–11 (in Dutch).

Moolenaar, S.W., Lexmond, T.M., 1998. Heavy metal balances of agro-ecosystems in the Netherlands. Netherlands J. Agric. Sci. 46, 171–192.

Moolenaar, S.W., Lexmond, T.M., 1999. Heavy metal balances. Part I. General aspects of cadmium, copper, zinc, and lead balance studies in agro-ecosystems. J. Ind. Ecol. 2, 45–60.

MRiRW and ARiMR, 2003. Polskie rolnictwo w UE. Biuletyn informacyjny, Wydanie specjalne, Ministerstwo Rolnictwa i Rozwoju Wsi, Agencja Restrukturyzacji i Modernizacji Rolnictwa, pp. 1–2, 1–68 (in Polish).

Nasreddine, L., Parent-Massin, D., 2002. Food contamination by metals and pesticides in the European Union. Should we worry? Toxicol. Lett. 127, 29–41.

Romaniuk, W., 1995. Gospodarka gnojowica i obornikiem. IBMER, Warszawa (in Polish).

Stoate, C., Boatman, N.D., Borralho, R.J., Rio Carvalho, C., de Snoo, G.R., Eden, P., 2001. Ecological impacts of arable intensification in Europe. J. Environ. Manage. 63, 337–365.

UKIE, 2003. Rolnictwo ekologiczne. Wydawnictwo UKIE, Warsaw (in Polish).

van Bruggen, C., Heijstraten, T., 2003. Transport en gebruik van mest en mineralen 1994–2002. Centraal Bureau voor de Statistiek, Voorburg, URL: http://www.cbs.nl/nl/publicaties/artikelen/milieu-en-bodemgebruik/milieu/index.htm (in Dutch).

van de Voet, E., Giunee, J.B., Udo de Haes, H., 1999. Metals in the Netherlands: a problem solved? CML-SSP Working Paper 99.003. Centre of Environmental Science, Leiden University, pp. 1–13.

van Noort, R.B.J.C., van Egmond, N.D., 2001. Dutch Environmental Data Compendium. Kluwer, Alphen aan den Rijn.

Wiersma, D., Van Goor, B.J., Van der Veen, N.G., 1986. Cadmium, lead, mercury, and arsenic concentrations in crops and corresponding soils in the Netherlands. J. Agric. Food Chem. 34, 1067–1074.