REGIONAL DIFFERENCES IN THE INPUTS OF CADMIUM TO SOILS

J. Keith Syers, Department of Natural Resources and Environmental Sciences,
Naresuan University, Phitsanulok 65000, Thailand, and
Limamoulaye Cisse, *Institut Mondial du Phosphate, Casablanca, Morocco*

INTRODUCTION

There are four external sources of cadmium (Cd) to agricultural soils: (i) atmospheric deposition, (ii) animal manure, (iii) sewage sludge (biosolids), and (iv) phosphate (P) fertilizers.

Atmospheric deposition is pervasive but is only a significant source close to smelters and urban areas (Tiller et al., 1994). Pearse (1995) estimated that atmospheric deposition accounted for approximately 50% of total Cd input to agricultural soils in Europe but emphasised that this was not the case for the North American Prairies and rural Australia.

Animal manure returned to the land can contribute significant amounts of Cd where heavy additions are repeatedly made to the same area (Johnston, and Jones, 1995), but this is not a major source of Cd, except in Western Europe. However, because manure is invariably generated on the farm where it is used, it should probably not be regarded as a Cd input source, per se, but rather as a 'transfer'.

Globally, sewage sludge or biosolids have not been a significant source of Cd input, although restrictions on dumping at sea and concerns regarding incineration may change this situation. At the same time, There are now Codes of Practice for the use of biosolids in agriculture (e.g., in Europe and USA) which restrict the loading of heavy metals, such as Cd. In the EU, there is a maximum permissible concentration of Cd in soil of 3 mg kg^{-1} with the average annual rate of Cd addition not to exceed 0.15 kg ha^{-1} each year over a ten-year period (Johnston and Jones, 1995).

Of the external sources of Cd, P fertilizers are the most regularly applied and are likely to add more Cd to soils if their Cd content is high. The accumulation of Cd in soils from long-term application of P fertilizers is now well established in several countries (Tiller et al. 1994). The Cd content of phosphate rock (PR) (and thus the P fertilizers derived from them) varies from around 1 mg Cd kg^{-1}P for Kola (Russia) (Singh (1991) to 640 mg Cd kg^{-1}P for Nauru (Syers et al., 1986). Single superphosphate contains essentially all of the Cd present in the PR, whereas high-analysis P fertilizers usually contain 60 to 70% of the PR Cd.

Comprehensive studies indicate that Australian soils have received 1.5 g Cd $ha^{-1}yr^{-1}$ for crops and 3.0 g Cd $ha^{-1}yr^{-1}$ for pastures from P fertilizers over the last 80 years (McLaughlin et al., 1996). These compare to values of 8.9 g Cd $ha^{-1}yr^{-1}$ in New Zealand (mainly pastures) (Bramley, 1990), 5.1 g Cd $ha^{-1}yr^{-1}$ for eight EU countries (Hutton, 1983), and 0.3 to 1.2 g Cd $ha^{-1}yr^{-1}$ (Mortdvedt, 1987) in the United States (mainly crops). Despite this information, there are limited data for Cd inputs at the national scale and this inevitably makes regional comparisons difficult.

The purpose of this paper is to compare the inputs of Cd in P fertilizers to arable soils in contrasting regions using FAO data for trends in P fertilizer use and changes in arable land area, along with assumed Cd concentrations for the P fertilizer used.

METHODOLOGY

Four regions (Africa, Asia, Europe, and South America), seven sub-regions within three of these regions, and one country (South Africa) were considered in this study. Details are given in Table 1. The reasons for the selection of these areas are the substantial differences in P consumption, in the Cd content of the P fertilizers used, and in the arable land area.

Table 1 : Regions (R), sub-regions (SR), and country(C) considered

Region/Sub-region/Country	Abbreviation used
1. Africa (R)	
(i) Sub-Saharan Africa (SR)	SSA
(ii) North Africa (SR)	NAF
(iii) South Africa (C)	SAF
2. South America (R)	SAM
3. Asia (R)	
(i) West Asia (SR)	WAS
(ii) South Asia (SR)	SAS
(iii) East Asia (SR)	EAS
4. Europe (R)	
(i) East Europe (SR)	EEU
(ii) West Europe (SR)	WEU

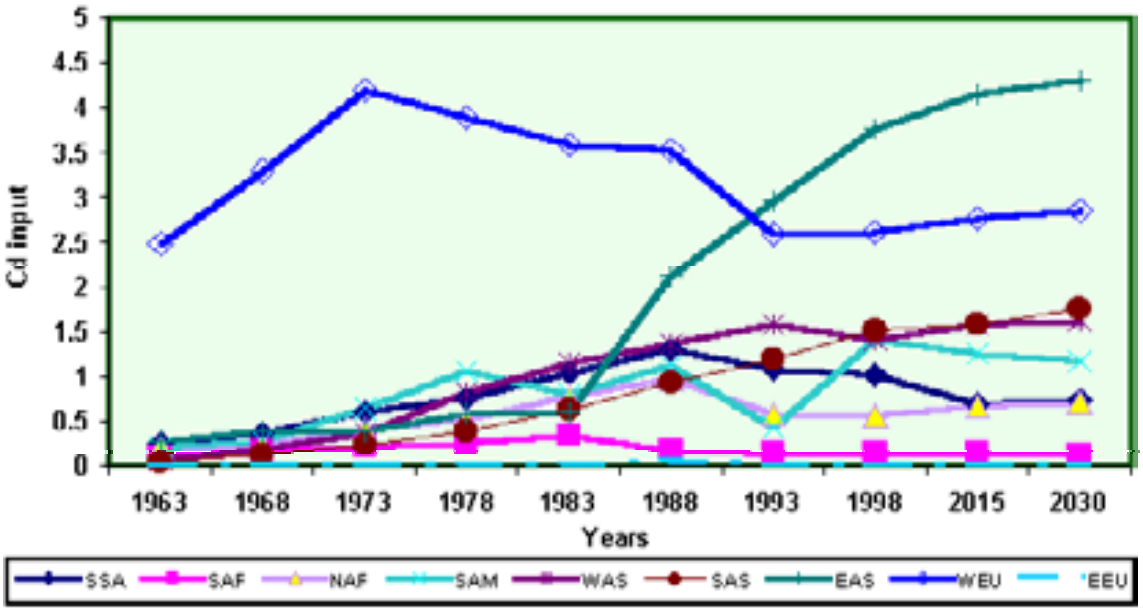
To estimate the changes in Cd inputs to agricultural soils from P fertilizers in different regions, sub-regions, or countries requires information on:
(i) trends in P fertilizer consumption
(ii) Cd content of the PR sources used
(iii) changes in arable land area

Data for trends in P fertilizer consumption and arable land area at five-yearly intervals during the time period 1963 to 1998 were taken from FAOSTAT (1999). The data for P fertilizer consumption are considered to be reliable. The FAO definition (FAOSTAT, 1999) of 'arable' land includes land under temporary crops, temporary meadows for mowing and pasture, land under market and kitchen gardens, and land under temporary fallow (less than five years). We have used FAO estimates of arable land area expansion from 1998 to 2030 of 25% for Sub-Saharan and South Africa, 13% for North Africa, 30% for South America, 13% for West Asia, 5% for South and East Asia, and 0% for West and East Europe.

The PR sources used in each region, sub-region, and in South Africa, along with their P and average Cd contents, are given in Table 2.

The average Cd input (g ha^{-1} yr^{-1}) to arable soils in each situation (Table 1) was calculated from P consumption data, weighting where possible for the different PR sources used (Table 2) and the values for average Cd contents (also in Table 2). The quantities of Cd were then expressed on a per hectare basis using the data for total arable land area in each situation. The results are shown in Figure 1.

Figure 1 : Inputs of Cd (g ha^{-1} yr^{-1}) in the region, sub-region, and country considered



These calculations involve certain assumptions. Where possible, in China within Asia for example, weighting was made for the use of local PR. In Western Europe, changes in major PR sources imported during the time period were taken into account (see footnote to Table 2). Also, it was assumed that all of the PR used to produce the P fertilizers used in East Europe was from Kola (Russia). Usually, the mean Cd content of the important (in terms of quantity) PR sources used and the total P used in a particular situation were considered in the calculation of Cd inputs. To trace and calculate the proportions of each P source used in each country, and thus the various sub-regions and regions, over the required time period is virtually impossible and almost prohibitive in terms of the amount of time required.

Thus the data presented in Figure 1 are estimates only of Cd inputs into arable soils.

RESULTS

The results presented in Figure 1 often show considerable variations in the inputs of Cd to arable soils, particularly for different situations at a given point in time, but also for a particular situation over time.

Table 2 : Phosphate rock sources considered and average Cd contents used for the calculation of Cd inputs to soils in various regions (R), sub-regions (SR), and South Africa (C)

Region/Sub-region/ Country	Phosphate rock sources	P content (%)	Average Cd content (mg Cd kg^{-1} P)
S. S. Africa (SR)	Senegal	16.0	563
	Togo	15.9	320
South Africa (C)	Phalaborwa	16.7	24.1
North Africa (SR)	Algeria	13.2	71.5
	Egypt	12.9	62.2
	Morocco	14.1	199
	Tunisia	13.1	250
South America (R)	Brazil	15.6	13.6
	Chile	7.6	65.8
	Peru	13.3	81.7
	Venezuela	11.9	42.0
	USA	12.8	295
West Asia (SR)	Israel	13.9	103
	Jordan	13.4	67.0
	Syria	13.3	37.8
South Asia (SR)	China	13.2	3.0
	Jordan	13.4	67.0
	Morocco	14.1	199
	Senegal	16.0	563
	Phalaborwa	16.7	24.1
	Tunisia	13.1	25.0
	USA	12.8	130
East Asia (SR)	Algeria	13.2	71.5
	China	13.2	3.0
	Jordan	13.4	67.0
	Morocco	14.1	199
	Thailand	12.8	49.9
	Tunisia	13.1	250
	USA	12.8	295
	Vietnam	13.7	1.4
East Europe (SR)	Kola	14.9	1.1
West Europe (SR)	Algeria	13.2	71.5
	Jordan	13.4	67.0
	Kola	14.9	1.1
	Morocco	14.1	199
	Senegal (1)	16.0	563
	Togo (1)	15.9	320
	Tunisia	13.1	250

(1) Data used only from 1962 to 1985, then removed from calculations of Cd input into soils in Western Europe.

Annual inputs of Cd in South Africa have changed little over the time period and are currently 0.14 g Cd ha^{-1}; these are not expected to change very much within the next 30 years because the projected increase in P fertilizer use will roughly be balanced by the anticipated increase in arable land area.

At the other extreme, annual Cd input has increased quite dramatically in East Asia since 1983, from a value of 0.5 g Cd ha^{-1} to 3.6 g Cd ha^{-1} in 1998. This is predicted to increase to 4.3 g Cd ha^{-1} by 2030. This calculation assumes that no PR from Vietnam (with a very low Cd content of 1.4 mg Cd kg^{-1} P, Table 2) is used. If it is assumed that 80% of the P consumption in East Asia is in China and that 75% of the P fertilizers used in China are produced from Chinese PR (with a mean Cd content of 3.0 mg Cd kg^{-1} P, Table 2) and the remaining 25% are produced from PR imported from Algeria, Jordan, Morocco, Tunisia, and USA, the calculated/predicted Cd input values for 1998, 2015, and 2030 are 1.5, 1.7, and 1.7 g Cd ha^{-1}, respectively.

Low and relatively constant (but probably declining) annual Cd input values are obtained/predicted for Sub-Saharan Africa, because the increase in land area is larger than that of P fertilizer consumption. The situation in South America is similar, although the Cd input values in 1998 are larger for South America, with a value of 1.1 g Cd ha^{-1} compared to 0.8 g Cd ha^{-1} for Sub-Saharan Africa. In contrast, a progressive increase in annual Cd input has occurred in South Asia, reflecting the substantial increases in P fertilizer use, particularly in India.

Annual Cd inputs to arable soils in West Europe increased steeply to approximately 4.2 g Cd ha^{-1} between 1963 and 1973, attributable to rapidly increasing P fertilizer use and a decreasing arable land area. After 1973, Cd inputs started to decline. Phosphate fertilizer use peaked in West Europe in 1973 and since then has decreased by an average of 2% per annum, or by nearly 50% from 1973 to 1998. Additionally, in 1985 use of the high Cd-containing rocks from Senegal and Togo (Table 2) was discontinued in West Europe, contributing to the decline in Cd input (Fig. 1). Currently, the calculated annual Cd input is about 2.5 g Cd ha^{-1} and this is expected to remain relatively constant, unless EU regulations change. If a meaned-out permissible Cd content for P fertilizers in West Europe of 100 mg Cd kg^{-1} P is taken in conjunction with a P fertilizer input of 1,627,400 tonnes of P (in 1998, FAOSTAT, 1999) and an arable land area of 76,925,000 ha (also for 1998, FAOSTAT, 1999), then an input of 2.1 g Cd ha^{-1} is obtained, which is similar to the value of 2.5 g Cd ha^{-1} obtained by taking into consideration the Cd contents of the different rock types used.

CONCLUSIONS

Preliminary analyses indicate that globally there is a wide variation in Cd input to arable soils from P fertilizers and thus generalizations of data and information from one region to another are fraught with danger. Operating at the regional level creates some difficulties and more comprehensive data are required at the national level.

Average annual inputs of Cd to arable soils in 1998 ranged from 0.14 g Cd ha^{-1} for South Africa to 3.6 g Cd ha^{-1} in East Asia. As Cd input (on a unit area) basis is obtaining by taking the product of P fertilizer use and the Cd content of the P fertilizer, and dividing this by the arable land area, variations in any one of these three parameters can affect Cd input. For example, in West Europe there has been a progressive decrease in P fertilizer consumption of approximately 2% per year between 1973 and the present, in conjunction with a decrease in arable land area and a change in the P rock sources used in 1985. This has resulted in a decrease in annual Cd input from 4.2 g Cd ha^{-1} in 1973 to 2.5 g Cd ha^{-1} in 1998.

In contrast, in South America, the recent and projected increase in P fertilizer use is more than compensated for by increases in the arable land area, resulting in a decrease in annual Cd input.

References

Bramley, R.G.V. (1990). Cadmium in New Zealand agriculture. New Zeal.J.Agric.Res; ***33****, 505-519.*

FAOSTAT. (1999). http//www.fao.org

Hutton, M. (1983). Sources of Cadmium in Europe, Inputs to Agricultural Land and Implications for Crop Uptake and Dietary Exposure. In Heavy Metals in the Environment. *Vol.* ***1****, pp. 430-433, CEP Consultants, Edinburgh.*

Johnston, A.E. and Jones, K.C. (1995). The origin and fate of cadmium in soil. Proc. Fert. Soc. *No.* ***366****, Fertiliser Society, London.*

McLaughlin, M.J., Tiller, K.G.. Naidu, R. and Stevens, D.P. (1996). Review: The behaviour and environmental impact of contaminants in fertilizers. Aust. J. Soil Res. ***34****, 1-54.*

Mortvedt, J.J. (1987). Cadmium levels in soils and plants from some long-term fertility experiments in the United States of America. J. Environ. Qual. ***16,*** *137-142.*

Pearse, J. (1995). Cadmium, Some Aspects of Risk Reduction. *Dutch Ministry of Housing and Spatial Planning and Environment. The Netherlands.*

Singh, B.R. (1991). Unwanted components of commercial fertilizers and their agricultural effects. Proc. Fert. Soc. *No.* ***312****, Fertiliser Society, London.*

Syers, J.K., Mackay, A.D., Brown, M.W. and Currie, L.D. (1986). Chemical and physical characteristics of phosphate rock materials of varying reactivity. J. Sci. Food Agric. ***37****, 1057-1064.*

Tiller, K.G., Oliver, D.P., McLaughlin, M.J., Merry, R.H. and Naidu, R. (1994). Managing cadmium contamination of agricultural land. In Iskandar, I.K. and Adriano, D.C. (Eds) Remediation of Soils Contaminated with Metals. *Advances in Environmental Science 225-255.*