Cadmium Flows in Recycling Waste to Agriculture in Thailand

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Abstract: *The heavy metal, cadmium is a toxic compound for all living organisms, and requires, therefore, special attention in risk assessment studies. As cadmium is a rather mobile ionic species under acidic soil conditions, which are dominant in Thailand's agricultural lowland, one could expect it to be present in agricultural crops. Consequently, it poses the potential risk of entering human food products. Research conducted over the last decades has found that rice, which is the main staple food item, is the main contributor to the human intake of cadmium in Asian countries. The objective of this study is to assess the change in risk when using treated biodegradable waste products as a substitute for chemical fertilisers in agriculture. Chemical analyses showed that the highest flow of cadmium in organic waste is in municipal wastewater sludge and biodegradable kitchen waste, whereas human excreta only carries small amounts of cadmium. Thailand does not presently have any regulation on this potential risk element, consequently international standards may be used for comparison. Recycling urban waste to agricultural land would, potentially, not exceed the American and European Union's threshold limit for waste application to agricultural soils. However, a few European countries (e.g. Denmark) have stricter threshold limits, due to specifically vulnerable soil and groundwater conditions (alkaline clay soils with the ability to accumulate heavy metals), and these would potentially be exceeded if some of the urban Thai wastes were applied to the soils. It is concluded that the recycling of urban waste to Thai agriculture poses only a very small potential risk of cadmium contaminated food products.*

Keywords: Recycling waste, cadmium, risk assessment, Thailand, Songkhla Lake Basin, mass flow

Introduction

Plant nutrients and organic material in soils are essential prerequisites for healthy plant growth and thereby food supplies. Depletion of plant nutrients (macro nutrients and micro nutrients) or organic material in soils may lead to severe agricultural as well as environmental problems, such as insufficient crop yields, economic recession, famine, soil erosion and desertification (Campbell, 1998; Gardner, 1997). The recycling of plant nutrients in biodegradable kitchen waste (from harvested crops and animal products) and in human waste back to agricultural areas (Figure 1) has for hundreds of years been the basic method for keeping the agricultural soils fertile (Esrey, 2001). However, during the last century extensive urbanisation, and consequently practical constraints in connection with the mentioned recycling, has led to a decreasing use of this ancient and natural method (Gardner 1997). Plant nutrients tend to enter a "one-way flow" direction out of rural areas and into urban waste (Figure 2), where inadequate handling methods often result in the local accumulation of nutrients as well as unhygienic and polluted living conditions for the urban population (Diaz et al., 1996; Esrey, 2001). Reversing this adverse development back to a sustainable development in relation to agriculture and urban sanitation[1] requires a fundamental rethinking of the possibilities for modern societies to handle the flow of nutrients from urban back to rural areas (Figure 1).

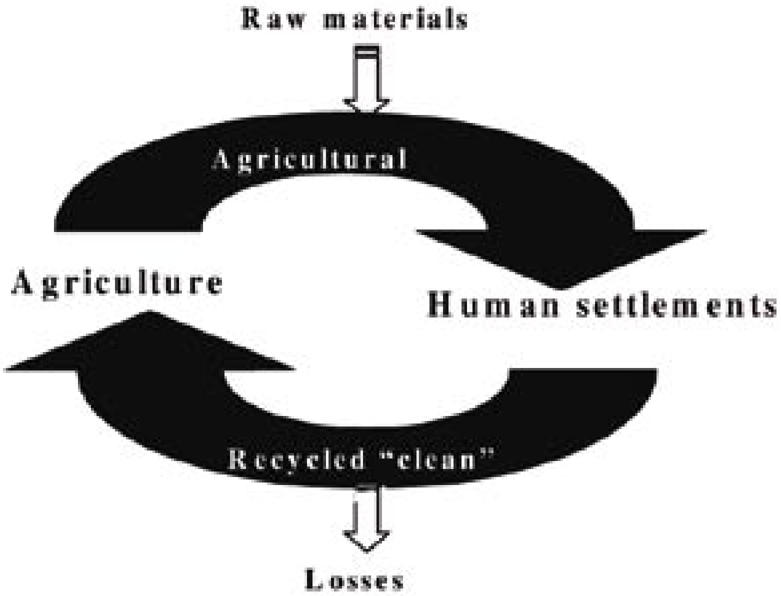

Figure 1. *Closing the nutrient cycle*

However there are several potential constraints to recycling of waste to agriculture, of which the threat to human health by recycling of pathogens and toxic chemical compounds are the most important. This paper studies the heavy metal contents of waste, and focuses on cadmium, as this is a very toxic metal accumulating especially in kidneys of humans impairing their function. It may also be toxic at elevated concentrations to other animals and plants. The human intake of cadmium with food in the Southern Thailand have been assessed by Schouw et al. in 2002b, estimating the intakes to between 20 and 40 µg per person per day. Cadmium intakes of this order approximate half of the provisional allowable intake. The intake is at the same level as found in European countries, where strict measures are introduced in order to curb further increases due to environmental pollution. It is well known that nearly all human cadmium intakes originate from agricultural soils as the metal is mobile in the soil-plant system. Thus the cadmium mass balance for the soils also determines the future changes in the human intake.

The purpose of this paper is to assess the changes in the load of cadmium to agricultural land, and thereby the human intake, if a substantial part of the present recyclable organic waste is brought back from urban areas for use in agriculture, i.e. as feed for domestic animals or as composted material replacing chemical fertilisers.

In most cases the nutrients and associated toxic compounds will eventually end up in the soil as manure or compost used as fertilising materials. The flow of cadmium in available waste is examined in three case study areas in Southern Thailand, and the risk of using the waste products in local agriculture directly or indirectly as a substitute for chemical fertilisers is assessed.

[1]Sanitation of solid waste, human excreta and sullage (wastewater from kitchen and bathroom).

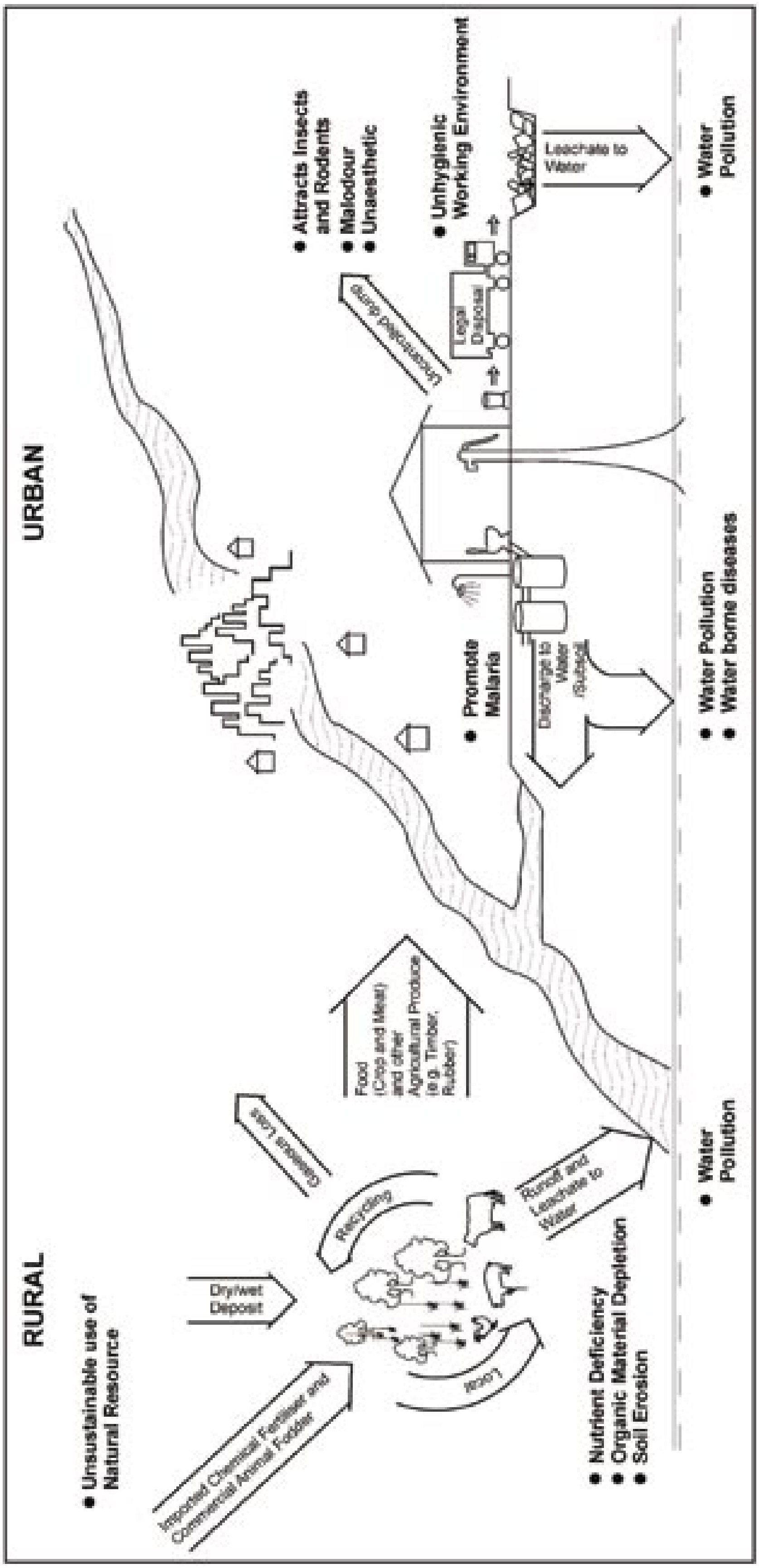

Figure 2. *Illustration of one way nutrient flow in typical Asian communities (text in arrows indicates transport means) and environmental problems caused (bold font) (Schouw 2002).*

Methodology

The Sites

It was chosen to focus this study on the Songkhla Lake Basin (SLB), as the mentioned pollution problems from inappropriate waste handling are particularly severe in this area. Additionally, this area is being used for extensive agriculture, supplying both the local population with food, and the export industry with produce (e.g. rubber, fruits and rice). An intensification of the agriculture over the last decades has led to an increased demand for nutrients partly met by purchases of chemical fertilisers.

Muang Phattalung, TAO Kuan Lang and Muang Prik were selected as specific case study areas (Figure 3) as they represent the Southern part of Thailand (Table 1). Thereby the findings of this study should

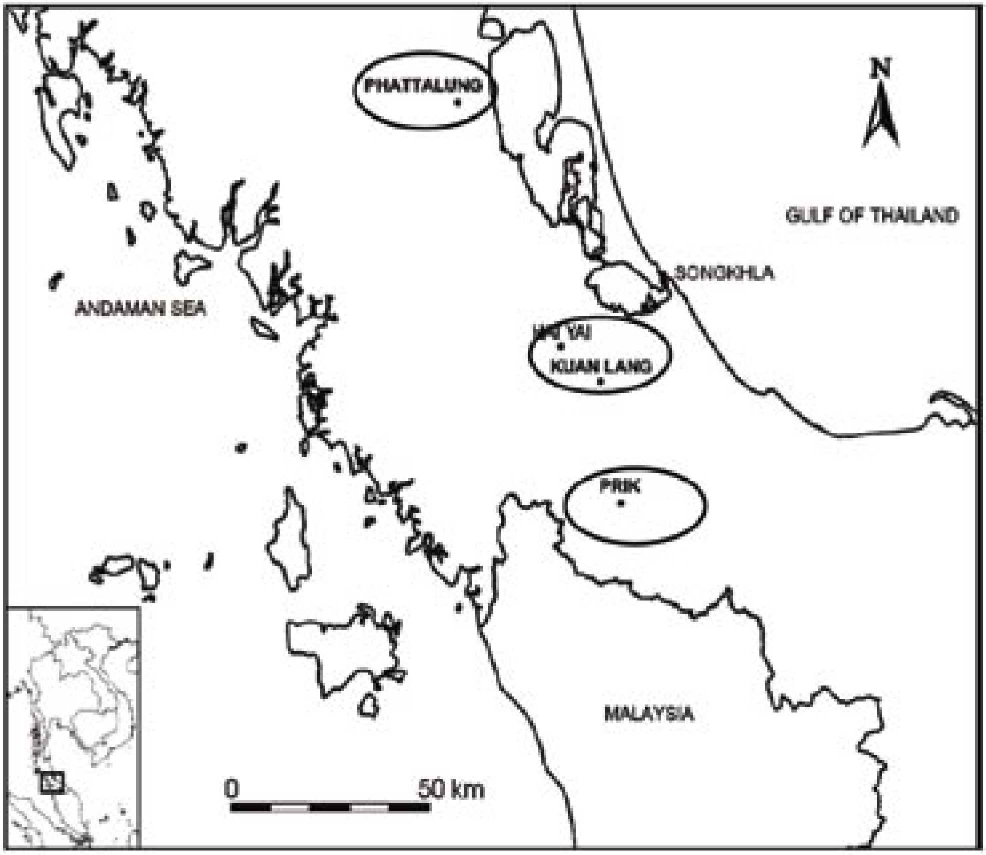

Figure 3. *Southern Thailand: the three case study areas.*

Table 1. *Characteristics of the three study areas (Schouw et al., 2002abcd)*

	Phattalung	Kuan Lang	Prik
Province	Phattalung	Songkhla	Songkhla
Area size, km^2	13.3	66.7	4.8
Population size	37,777	26,266	5,926
No. of household	10,978	3,422	925
Administrative level	Municipality	TAO[1]	Municipality
Community level	Urban	Peri Urban	Rural
Income, Baht/cap/yr	18,874	23,463	19,996

[1] Tambon (~village) Administrative Organisation

be partly applicable to most other communities of Southern Thailand.

Sampling

To study the flow of cadmium in human settlements, representative samples of solid biodegradable waste and wastewater were collected at the waste generating sources (industry, fresh food market, restaurants) as well as biodegradable kitchen waste, grey wastewater and human excreta from households. For detailed information on sampling methods and selection criteria for the representative waste generating sources confer to Schouw et al., 2002a,b.

Analysis

The waste samples were *inter alia* analysed for cadmium. The wet waste samples were dried at 75ºC for 3-5 days, until constant weight. All dried solid waste samples (0.2 g dry matter) and wastewater samples (25 ml) were digested in 15 ml acidic reagent (1,250 ml conc. HNO_3 and 250 ml conc. $HClO_4$ and 0.06 g NH_4VO_3) during a stepwise temperature increase from 80ºC to 190ºC. The volume of the digested solution was finally adjusted to 50 ml. All human excreta samples were dried in an oven at 70ºC for 4 days, and then digested using 2 g DM in 60 ml conc. HNO_3 and 1ml $HClO_4$ (60%) in conical flasks on a hot plate. After heating for 3 – 4 days the remaining volume was adjusted to 50 ml by addition of de-ionised water.

An atomic absorption spectrophotometer with graphite furnace (Perkin Elmer AAnalyst 600) was used to analyse cadmium using standard conditions. Problems with respect to upper or lower detection limits were avoided by diluting or increasing the quantity of sample being analysed.
Blank samples were included in each analysis series. An internal reference sample, homogenised grass pills, was further included in each analysis series (SRM 1571).

Results

The flows of cadmium in potentially recyclable biodegradable waste (solid biodegradable waste, grey wastewater and human excreta) from three typical representative human settlements in Southern Thailand are illustrated in figures 4-6.

Phattalung Cadmium Balance

In Phattalung the main cadmium source in waste is grey wastewater from households (Figure 4). Grey wastewater from households, restaurants, canteens, markets, and industry are discharged via gutters and a river into the Songkhla Lakes. The toilet septic tanks are connected to conventional drainage pits, which infiltrates the liquid phase of the human excreta to the subsoil and groundwater. About 1/3 of the biodegradable kitchen waste from households and most food waste from the fresh food markets are collected by pig farmers around Phattalung and reused as animal fodder. The rest is disposed at a landfill site.

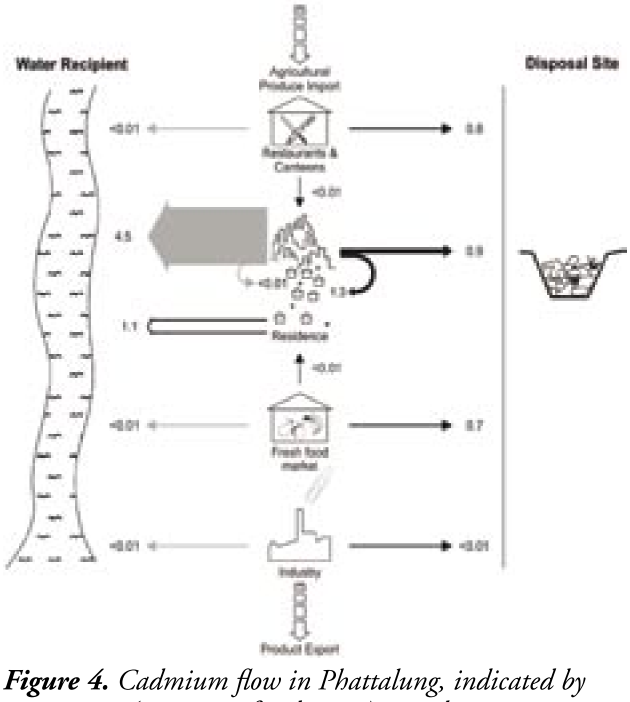

***Figure 4.** Cadmium flow in Phattalung, indicated by arrow sizes (quantity of cadmium), numbers at arrows (kg Cd per year) and arrow shading (grey: wastewater; white: human excreta; black: solid waste).*

Kuan Lang Cadmium Balance

Most cadmium is being generated via the waste from grey wastewater and industry (rubber glove factory) in Kuan Lang (Figure 3).

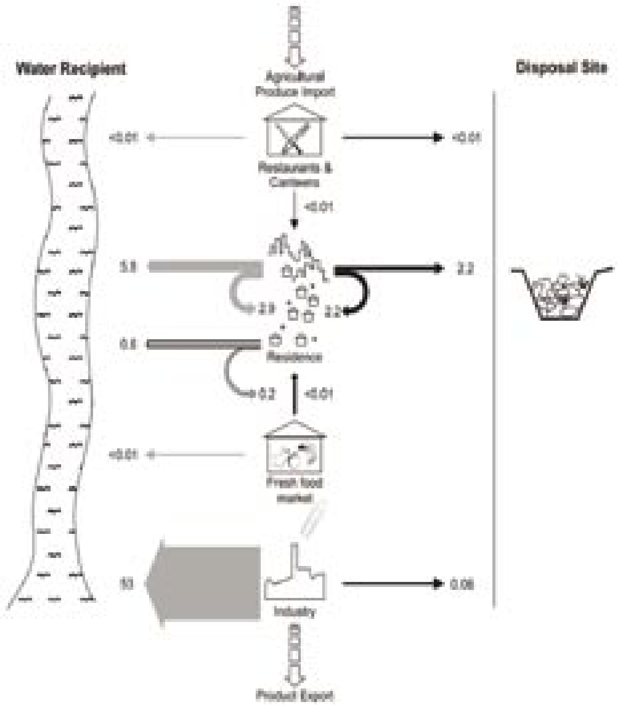

Figure 5. Cadmium flow in Kuan Lang, indicated by arrow sizes (quantity of cadmium), numbers at arrows (kg Cd per year) and arrow shading (grey: wastewater; white: human excreta; black: solid waste).

Kuan Lang also uses the conventional Thai septic tank toilet system, but around 30% of the householders empty their own tanks and recycle the septic sludge into private gardens (Schouw et al., 2002d).

Sullage is discharged to stagnant water pools in ditches from where it slowly penetrates into the sub soil. Around 35% of the householders recycle sullage by watering their garden crops (Schouw et al., 2002d).

Solid household waste is mainly dumped or buried in the private gardens as the conditions of the roads do not allow municipal trucks to collect the waste (Schouw et al., 2002a). The industrial wastewater is discharged to the river via a treatment plant reducing the organic content.

Prik Cadmium Balance

The sawdust from the timber factory and the grey wastewater are the dominant cadmium sources in waste in Prik (Figure 6).

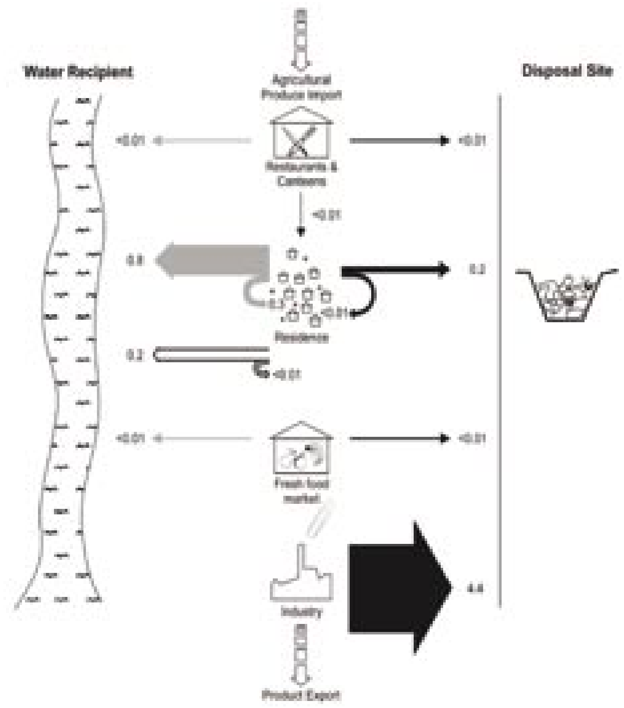

Figure 6. Cadmium flow in Prik, indicated by arrow sizes (quantity of cadmium), numbers at arrows (kg Cd per year) and arrow shading (grey: wastewater; white: human excreta; black: solid waste).

The industrial sawdust is deposited together with the main fraction of the solid household waste at a landfill site outside Prik.

The human excreta are handled in similar ways as in Kuan Lang and Phattalung, only with a minor fraction (6%) being reused for fertilising fruit trees in private gardens (Schouw et al., 2002d).

Sullage is recycled as irrigation water by 30% of the householders in Prik, and the remaining fraction is infiltrating the soil or discharged via ditches to rivers (Schouw et al., 2002d).

Cadmium Concentrations in Potentially Recyclable Waste Materials and in Fertilisers

The quality of organic waste materials, which potentially may be recycled to agriculture from the three settlements, is found in Table 2. The total concentrations of cadmium and phosphorus are shown, and the ratios between the toxic cadmium and the plant nutrient phosphorus are calculated.

Table 2. *Cadmium content in various potentially recyclable waste fractions in Southern Thailand.*

Item	**mg Cd/kg DM**	**mg Cd/kg P**	**Reference**
Kitchen waste	0.65	539	Schouw et al., 2002a
Grey wastewater	0.002	85	Schouw et al., 2002a
Human excreta	0.26	15	Schouw et al., 2002b
Sewage sludges	1.22	1060	Parkpain et al., 2000
Sewage sludges, Bangkok	2.5-3.8[1]	200-350[3]	Namatra & Manmee 2002
Rubber industrial wastewater	0.034	1800	Schouw et al., 2002a
Rubber industrial solids waste	14.76	36900	Schouw et al., 2002a
Fresh food market solid waste	1.72	400	Schouw et al., 2002a
Saw dust	0.6	1500	Schouw et al., 2002a
Canteen waste	1.32	600	Schouw et al., 2002a
Chemical fertilisers sampled	-	0-400[3]	Schouw et al., 2002a
Chemical fertilisers used in SLB	-	1.4-30 (8.6)[1]	Sae-Eong, 2002 & Sereewatthanachai 2002
Cultivated soils in SLB	0.001-0.09 (0.025)[1]	250	
Non-cultivated soils in SLB, range	0.001-0.002[1]	50	
Fertiliser limit, DK	-	100	MST 2000
Sludge use, guideline, EU	10	250	EC 2000
Compost use, guideline, EU	0.7-5[3]	-	EC 2001
Organic waste, guideline, DK	0.8	200	MST 2000

Concentration range (average in bracket)

Cadmium and Phosphorus Flows with Fertiliser into Agriculture Lands

There have only been few attempts to quantify the phosphorus and cadmium inflow to the region. Table 3 shows some recently reported results for the most likely inputs of phosphorus and cadmium to agricultural land in the Songkhla Lake Basin in the Southern Thailand. It is evident that the cleanest fertilising material is the fertiliser in use, followed by the human excreta. The grey wastewater can provide

Table 3. *Recently reported results for the inputs of phosphorus and cadmium to the Songkhla Lake Basin. Results are recalculated as inputs per person and year*[1]

Waste	**Generation kg P/p.y**	**Generation mg Cd/p.y**	**Average Cd/P**	**Cd in DM**	**Reference**
Kitchen waste	0.06	22	350	0.65	Schouw 2002a
Grey wastewater	0.9	75	70	-	Schouw 2002a
Human excreta	0.6	9	15	0.26	Schouw 2002a
Fertiliser use in SLB	1.3	11	8.6	n.a.	Sereewatthanachai 2002; Sae-Eong 2002
Fertiliser, max.	1.3	130	100	n.a	See table 2
Aerial input, min.	~0.020	50	~2500	-	Sereewatthanachai 2002

[1] Assumptions: average population density on available agricultural land is 700 persons/km^2; all human excreta are brought back to land; other organic waste with a Cd/P ratio less than 200, or having a maximum Cd concentration of e.g. 1 mg/g DM from this population may be brought back to that land; the shown value for the aerial input is derived from experience in Europe.

fair amounts of phosphorus, still with a reasonable quality. Kitchen waste is low in fertiliser potential and somewhat contaminated. The fertiliser quality is unusually high (Imported from Russia, Kola Peninsula), and this may change if suppliers change.

Discussion

The cadmium concentrations in the organic waste from the settlements in the Songkhla Lake Basin vary considerably depending on the origin and the possibilities of getting polluted. Apart from industrial waste the grey waste water and human excreta are the major carriers of nutrients out of the households, while they hold only minor concentrations of cadmium.

The concentration in the excreta reflects closely the human ingestion of the metal. The other organic wastes have higher concentrations of cadmium in the dry matter. The few sewage sludges (not from the SLB) examined appear not to be excessively contaminated with cadmium, but do not either have high concentrations of nutrients, i.e. phosphorus.

Generally, the mass flow studies in the Songkhla Lake Basin show that the major part of cadmium in urban waste is generated in the industrial waste and the grey household wastewater, which apart from the recycled waste mostly ends up in water bodies. Cadmium flow in human excreta is quite low and is mainly discharged to deep drainage pits via the septic tank systems.

If waste is considered as a useful fertilising material, the inorganic toxicological quality of waste should be examined. The ratio Cd/P is in use in the European countries and may be considered as one of the future quality parameters in Thailand. The ratio is one of several useful parameters when assessing alternative fertilising material, i.e. the origin of chemical fertiliser, or the management of waste materials, which might be useful in agriculture as fertiliser or feed for animals. Apparently, there are no specific guidelines in Thailand regulating the use of waste materials for agricultural use. Most industrialised countries have introduced rules and regulations for the activity. When comparing the existing regulation for the EU and Denmark, only the use of contaminated industrial waste and kitchen waste seem problematic.

The flow of cadmium in agriculture in the Songkhla Lake Basin undertaken by Sereewatthanachai 2002, and Sae-Eong 2002 may be used in assessing the impact of using organic waste as supplement/substitute for chemical fertilisers. This is attempted in table 2. They also found that the soils of the Songkhla Lake Basin are very acid, ranging in pH 3.8-4.0 for uncultivated soils and 3.6-5.7 for cultivated soils. At low pH, the mobility of cadmium in the soils is high and rather quickly the inputs (precipitation, fertiliser and manure) come to equal the outputs (cropped plants and leaching). This means that the average and quasi-stationary cadmium concentrations in the acid soils are low and thus the average retention time in the soil is equally low. It also means that an increase in cadmium inputs in a few years will lead to a proportional sized increase in plant concentrations if other conditions are kept constant. Likewise, a decrease in input to soils may lead to cleaner plants in a few years. So, it is fairly important to ensure that the annual input of cadmium will not be excessive.

Conclusion

From our results it is safe to say that the fertiliser in use in the Songkhla Lake Basin is unusually clean, and that the possible alternative fertilising materials (human excreta and grey waste water) in quality are well above the acceptable according to European guidelines for use of waste in agriculture. Thus reuse of these wastes as fertiliser on soils will not pose a risk of contaminating crops with toxic cadmium.

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