Improving waste management in protected horticulture

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Research article

Improving waste management in protected horticulture

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Abstract – One of the greatest problems associated with greenhouse horticulture is the amount of solid waste e.g. steel, plastics and non-yield biomass, that it produces. In this study, we used life cycle assessment (LCA) to evaluate the environmental burdens associated with crop processes and to investigate the relative importance of different waste management options applied in protected horticulture. Four waste management scenarios were analysed: (a) non-yield biomass was composted and other materials were disposed of in landfill; (b) all waste was disposed of in landfill; (c) all waste was incinerated; and (d) non-yield biomass was composted and other materials were incinerated. The study revealed that source segregation followed by the composting of biodegradable matter was the best way of managing waste to improve the impact assessment for most impact categories considered. Segregation of non-yield biomass and its composting reduced the environmental burden for most of the impact categories considered, reaching its maximum value in the category of climate change, which it was possible to reduce by between 40% and 70% depending, respectively, on the option considered; landfill or incineration.

compost / greenhouse / incineration / landfill / LCA / tomato

1. INTRODUCTION

Recent years have seen an expansion in greenhouse horticulture in the Mediterranean area. Due to favourable climatic conditions it is possible to grow crops in low-technology greenhouses, which require fewer resource inputs than more complex greenhouses. However, one of the problems associated with this system of production is the large amount of solid waste produced: steel, plastics and non-yield biomass.

Lately, there has been an increase in the use of re-circulated or closed systems in order to reduce pollution associated with the use of fertilisers and to save water. These are growing systems in which the water drained from the root zone is collected and reused to irrigate the same crop. However, "soilless" closed systems require more material: benches, collection pipes, bags of substrate, soil covering film, etc., which also generate a significant quantity of waste.

At their "end of life", these materials have been traditionally incinerated or disposed of in a landfill. Some companies recycle these plastics, but recycling costs are highly variable; they not only depend on the material in question, but also on such market-determined factors as the price of the materials made from primary sources and the quality and quantity of the material available for recycling. The recycling of plastic is generally more expensive than the market price of the recycled product, and therefore this needs to be subsidised.

In addition, there is a non-yield biomass of 10 000 to 30 000 kg of dry matter ha^{-1} $year^{-1}$, depending on the crop in question. Various options are available for the treatment of this non-yield biomass; landfill disposal or incineration if there is no segregation from other materials, or composting or related anaerobic digestion processes if segregation is carried out.

The European Union Landfill Directive (EC, 1999) required member states to take measures to reduce biodegradable waste disposal in landfills to 75% of 1999 levels by 2004 and to 35% by 2014. It is clear that the recovery and recycling practices currently applied in Europe are unable to reach the targets set by this directive unless composting is adopted as a means of organic recycling on a commercial scale (Ren, 2003).

This paper presents the results of an analysis involving different waste management scenarios: landfill disposal, incineration and the composting of waste. Previous work (Antón, 2004) has underlined the importance of waste management within the global process of greenhouse tomato production.

2. MATERIALS AND METHODS

Life Cycle Assessment (LCA) was used to assess the environmental burdens associated with crop processes and the importance of different waste management procedures used in

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Table I. Waste generated by tomato crop grown under greenhouse conditions, expressed as g of waste per kg of tomato (Antón, 2004).

	$g{\cdot}kg_{tom}^{-1}$
Non-yield biomass (dry weight)	43.5
Low density polyethylene (greenhouse cover and soil cover)	6.79
Polyethylene (fastening bars, watering equipment)	5.9
Polystyrene (benches)	2.9
Steel (greenhouse structure)	13.3

protected horticulture. LCA is a tool for assessing the environmental aspects and potential impacts associated with a given product or system (Audsley, 1997; Guinée et al., 2002).

A tomato crop was cultivated in a traditional Mediterranean steel-frame greenhouse with a low-density polyethylene film (LDPE) cover. Plants were grown in a closed system with recirculation of nutrients. The waste generated by a tomato crop grown under greenhouse conditions is shown in Table I. Values are expressed as weight of waste per kg of tomato produced and classified according to the different materials involved. These values were calculated for a 2000-m^2 greenhouse and take into account the lifespan of the different materials. They related to a crop of tomato over a period of six months, which produced 15 kg of salad tomato per m^2. Plastics were renewed every three years and the lifespan of the steel structure was taken to be 20 years.

In order to facilitate study, the process of tomato production was analysed in terms of three different systems: (1) MANUFACTURE: manufacture of the different materials that comprise the greenhouse structure and equipment; (2) TOMATO PRODUCTION: including crop management and fertiliser and pesticide production; and (3) WASTE: disposal of the different solid waste products (steel, plastics and non-yield biomass). More information about systems 1 and 2 can be found in Antón et al. (2005).

Four scenarios for waste management were analysed: (a) non-yield biomass was composted and other materials were disposed of in landfills; (b) all waste was used as landfill; (c) all waste was incinerated and (d) non-yield biomass was composted and other materials were incinerated.

The following impact categories, which are typically used in LCA (Audsley, 1997; Guinée et al., 2002), were assessed: IPCC-Climate change (CCI, g eq. CO_2); WMO-Depletion of the ozone layer (DOI, g eq. CFC-11); WMO-Photochemical oxidant formation (POI, g eq. ethylene); ETH-Air Acidification (AI, g eq. H^+); BR-Depletion of abiotic resources (AR, yr^{-1}); CML-Eutrophication (EI, g eq. PO_4); CST-Human toxicity (HTI, g eq. Pb air); aquatic ecotoxicity (ATI, g eq. Zn water) and terrestrial ecotoxicity (TTI, g eq. Zn air).

Tomato production in kg was selected as the functional unit. The functional unit describes the primary function performed by a product system: in this case, it provided a reference against which input and output data were compared and standardised in the mathematical sense (ISO-14040, 1997).

For all scenarios, the transport considered was a 16-ton lorry with a carrying capacity of 5 m^3. We considered a distance of 30 km from the greenhouse to the different waste disposal sites.

Data relating to emissions and energy used by incineration plants and in landfill disposal were obtained from the DEAM® (Ecobilan, 1999). This database contains data about the incineration and landfill disposal of wood. The following factors must be taken into consideration when obtaining data relating to emissions of non-yield biomass:

- Wood composition was $C_{295}H_{420}O_{186}N$, while biomass composition was considered to be $C_{27}H_{38}O_{16}N$ (Haug, 1993): therefore C/N rates were, respectively, 252.8 for wood and 23.2 for biomass. Decomposition in landfill was determined on the basis of the different biopolymer structures, the different humidity contents, and the respective C/N rates. As a result, the DEAM® data had to be corrected, taking into account the fact that N rates were ten times higher for biomass than for wood.
- Agricultural waste is more biodegradable, with an average life of 2.8 years, than wood, which biodegrades in 10.5 years (ECON, 2000). It also has higher humidity content.
- The proportion of the anaerobic decomposition of "glucose" was used to calculate anaerobic decomposition of biomass: one mol of $C_6H_{12}O_6$ produced three mols of CO_2, and three mols of CH_4, resulted in 132 g of CO_2 and 48 g of CH_4. Following this approach, one mol of non-yield biomass, $C_{27}H_{38}O_{16}N$ (Haug, 1993), produced 594 g of CO_2 and 189 g of CH_4.

Composting implies the aerobic degradation of waste to produce compost, which can then be used to improve soil quality. We used data from the San Cugat tunnel compost plant (AGA, 2002) to calculate the environmental burden associated with composting, applying the compost analysis values provided by the same plant (Tab. II)

The compost generated was used in extensive farming and the application of other mineral fertilisers was avoided. The following aspects were considered when calculating the avoided environmental burden: savings in mineral fertilisers depend on such factors as the crop in question and the specific soil conditions, etc. In some cases, applying compost at the beginning of crop production is sufficient in itself, while in others, it is necessary to complement such applications with those of other mineral fertilisers. The dose of compost applied was decided on the basis of its nitrogen and organic matter content (Soliva, 1998). In this sense, doses of other elements could have been excessive or insufficient and therefore sometimes needed to be corrected. Following AGA (2002), in our calculations we assumed that applying compost implied a 50% saving in the application of mineral fertilisers.

Due to lack of data, this study did not consider non-fossil carbon sequestered in the earth's surface as a result of the use of compost.

The use of compost produces a loss of nitrogen due to lixiviation, though its importance depends on the type of soil involved, the process of decomposition, and the mineralisation of nitrogen. In this study, 10% of the nitrogen applied was considered lost (Audsley, 1997).

The phosphorus contained in compost is mainly insoluble (Rovira, 1997) due to its high calcium content and has a slightly high pH. Its application on our soils, which tend to also have high calcium content, did not cause a loss of lixiviates. Even so, 2% was considered lost due to runoff or percolation.

Table II. Composition of reference compost expressed as dry matter (AGA, 2002). * ITEQ: dioxin toxic equivalents due to dibenzodioxins and dibenzofurans.

	Values	Units
Compost obtained	390	kg·t^{-1} waste
Metals (Cd, Cr, Cu, Hg, Ni, Pb y Zn)	422	mg·kg^{-1} compost
Calcium (Ca)	71000	mg·kg^{-1} compost
Nitrogen (N)	28000	mg·kg^{-1} compost
Potassium (K)	15000	mg·kg^{-1} compost
Magnesium (Mg)	6000	mg kg^{-1} compost
Phosphorus (P)	7000	mg·kg^{-1} compost
Iron (Fe)	11000	mg·kg^{-1} compost
Micro-contaminants		
Dioxins	29.38	ng ITEQ*·kg^{-1} compost
Polychlorinated biphenyls (PCB)	14.2	µg·kg^{-1} compost
Polycyclic aromatic hydrocarbons (PAH)	9020	µg·kg^{-1} compost
Chlorobenzenes	53.5	µg·kg^{-1} compost
Chlorophenols	27	µg·kg^{-1} compost

3. RESULTS AND DISCUSSION

Table III shows the absolute values for each of the different systems considered; manufacture of the greenhouse structure and equipment; tomato production; and waste management, for the different waste management scenarios. Results are expressed in g equivalent per unit relevant for each impact category. In addition, percentages for the waste contribution of each scenario with respect to the total (manufacture plus production plus waste) are provided in brackets.

The results for comparisons of the environmental impact produced by the different waste scenarios show the importance of waste management. The negative environmental burden was calculated for the scenario in which biomass was composted and compost was reused. Other waste products, such as plastics and steel, were disposed of in landfills giving results whereby this (WASTE) system contributed almost 20% of the global impact of the greenhouse tomato crop process in the categories of eutrophication and climate change (Tab. III). In the case of landfill disposal of all waste, the environmental impact of WASTE within the global process increased to 94% for the climate change category, 50% for eutrophication, and almost 40% for the category of photochemical oxidant formation (Tab. III). When all waste was incinerated, the climate change category was 67% affected by the WASTE subsystem. In scenario 4; biomass compost and incineration of other wastes, the contribution of the WASTE system to climate change was 44%, and 23% for eutrophication.

Comparisons of absolute values for the WASTE subsystem between different scenarios (Fig. 1) showed that landfill disposal was the greatest contributor to the eutrophication, climate change and photochemical oxidant categories. Emission of greenhouse gases such as CH_4 and CO_2 generated by the biomass at the landfill were responsible for the increase in climate change. Eutrophication also increased in the landfill scenario due to leachates.

Nevertheless, in the global analysis, some of the results were masked due to the importance of other systems, and particularly due to those related to toxicity. Waste incineration generated ten times higher levels of human toxicity than landfill disposal. This ratio was 4.3 times higher for terrestrial ecotoxicity, while aquatic ecotoxicity was lower in the incineration scenario (Fig. 1).

Table IV shows the most significant emissions caused by the different types of waste management: units are expressed as g of substance released by the material used, per kg of tomatoes produced.

Emissions of heavy metals to air are usually the result of incineration, while emissions to water are normally the result of the decomposition of plastics at the landfill. The heavy metals Hg and Pb were emitted from the incineration of plastics. As reference values it is useful to note that emissions of Hg and Pb to air in Europe during the year 2000 were 1.6E+08 g and 1.2E+10 g, respectively. Aquatic ecosystems were affected by emissions of Pb deriving from the incineration of polyethylene, and of other metals such as Cd, Cu, Hg and Zn generated during the decomposition of these materials at the landfill. The reference values for emissions of heavy metals to water in Europe were 2.1E+07 g Cd, 1.7E+09 g Cu, 1.4E+07 g Hg and 1.1E+10 g Zn. Even so, results relating to heavy metals must be carefully evaluated as a first approach because there can be significant variations between one database and another. For this study we used data from the DEAM® database.

4. CONCLUSION

The study shows that source segregation followed by the composting of biodegradable matter is the best way to manage waste and improve the impact assessment for most of the impact categories considered. Segregation of non-yield biomass and its subsequent composting reduces the environmental

Table III. Absolute values in the respective units of each category for the different impact categories for manufacture, the tomato production system and the four waste management scenarios considered: (a) non-yield biomass was composted and other materials were deposited as landfill; (b) all waste was deposited as landfill; (c) all waste was incinerated; and (d) non-yield biomass was composted and other materials were incinerated. In brackets, percentage of waste scenario with respect to the total process (MANUFACTURE + TOMATO PRODUCTION + WASTE) CFC: chlorofluorocarbon.

		MANUFACTURE	TOMATO PRODUCTION	WASTE							
				a) compost +landfill	(%)	b) landfill	(%)	c) incineration	(%)	d) compost + incineration	(%)
Eutrophication	g eq. PO_4	3.8E–02	4.1E–02	2.1E–02	(21.4)	8.0E–02	(50.4)	4.1E–03	(4.9)	2.3E–02	(22.8)
Depletion of non-renewable resources	yr^{-1}	1.9E–02	4.4E–03	–1.5E–04	(-0.6)	2.7E–05	(0.1)	2.8E–05	(0.1)	–1.4E–04	(–0.6)
Air acidification	g eq. H^+	1.4E–02	1.3E–02	7.1E–05	(0.3)	7.8E–04	(2.8)	9.0E–04	(3.2)	5.2E–04	(1.9)
Climate change (direct, 20 years)	g eq. CO_2	7.3E+01	–8.7E+00	1.7E+01	(20.6)	1.0E+03	(94)	1.3E+02	(67)	5.0E+01	(43.5)
Depletion of the ozone layer	g eq. CFC-11	2.6E–06	1.5E–05	6.0E–07	(3.3)	7.7E–07	(4.2)	8.3E–07	(4.5)	8.3E–07	(4.5)
Photochemical oxidant formation	g eq. ethylene	1.2E–01	4.5E–02	1.8E–03	(1.1)	1.1E–01	(39)	2.3E–03	(1.4)	9.8E–04	(0.6)
Aquatic ecotoxicity	eq. Zn water	2.2E–03	5.1E+00	2.5E–01	(4.7)	2.5E–01	(4.7)	1.3E–01	(2.5)	1.3E–01	(2.5)
Human toxicity	eq. Pb air	4.7E–01	3.9E+04	1.3E–01	(0.0)	1.5E–01	(0.0)	1.5E+00	(0.0)	1.4E+00	(0.0)
Terrestrial ecotoxicity	eq. Zn air	5.0E–05	1.3E+02	5.7E–05	(0.0)	7.4E–05	(0.0)	3.2E–04	(0.0)	2.8E–04	(0.0)

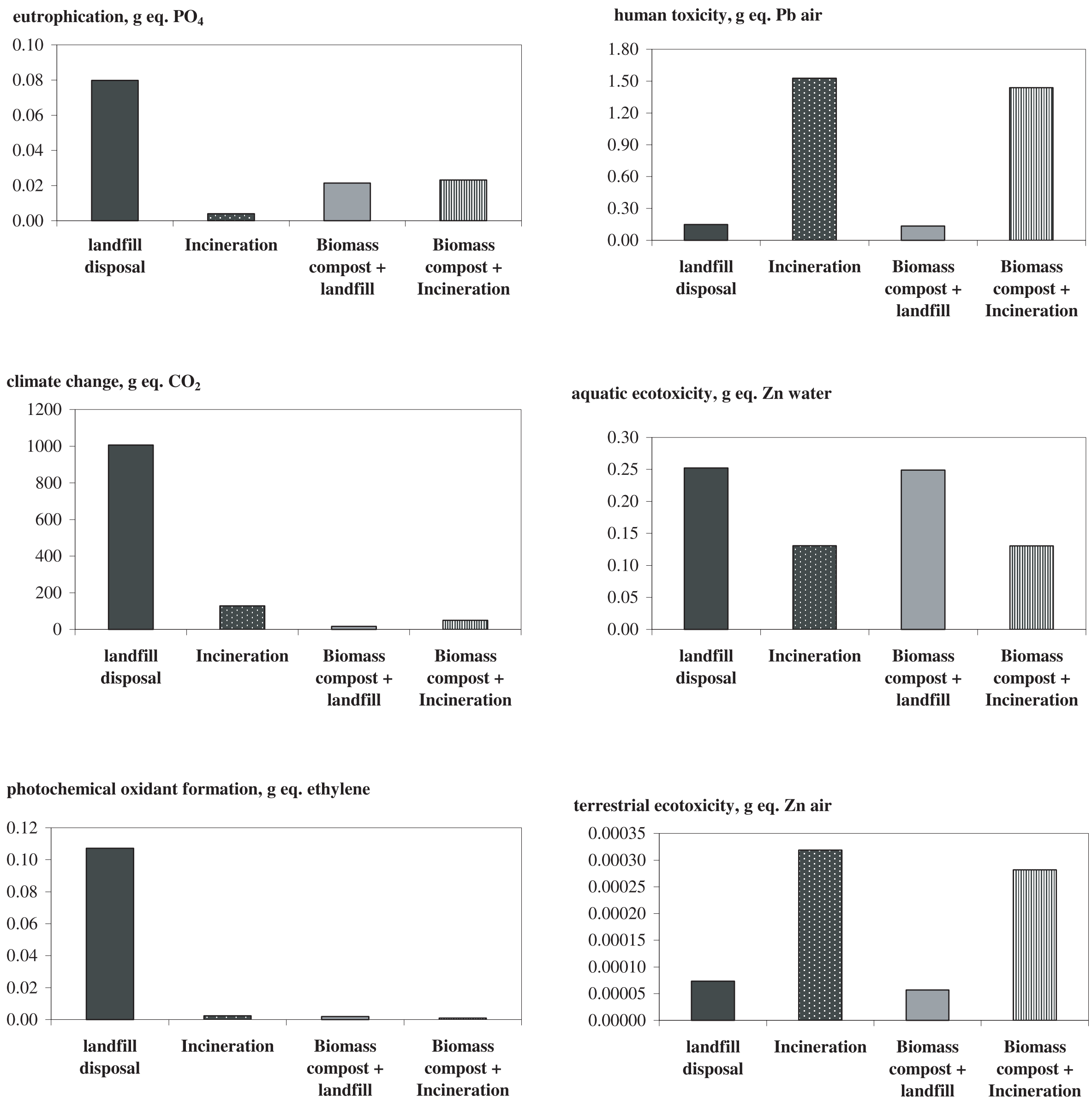

Figure 1. Contribution of waste system in absolute values for different impact categories. Landfill disposal is the greatest contributor to the eutrophication, climate change and photochemical oxidant categories. Incineration showed the highest values for human and terrestrial ecosystem toxicity while aquatic ecotoxicity was lowest for the incineration scenario.

burden of most of the impact categories considered. This reaches its maximum value in the category relating to climate change, where the impact was reduced by between 40% and 70%, depending on the particular option considered; landfill or incineration.

Though toxicity categories are somewhat masked by pesticide toxicity, landfill disposal increases emissions of heavy metals to water, which can in turn affect aquatic ecosystems. Incineration increases emissions to air, which affect human and terrestrial ecosystem toxicity.

Both landfill and incineration present significant environmental problems for non-biomass waste. In this sense, it is important to develop policies to reduce residues from used materials and recycle and improve the durability of materials used in the structure and equipment.

Compost reclamation could increase eutrophication due to the leachate of nutrients. Improving compost quality and management at compost plants in order to offer a high quality product should also be a major priority.

The validity of these results depends, of course, on the certainty of the assumptions and the accuracy of the data used. Aspects that deserve further consideration include recovering landfill gases and biogases and thereby reducing greenhouse gas emissions and improving current incineration processes. Further research must be carried out into the use of biodegradable and recycled materials and their uses must be quantified.

Table IV. Emissions of the main substances to air and water expressed in $g \cdot kg_{tom}^{-1}$: values for the different materials arranged according to waste management scenario, landfill, incineration or compost and the categories affected. Values in bold and italics represent the highest contributions. The final column identifies the impact categories affected by these emissions: CCI: Climate change; POI: Photochemical oxidant formation; AI: Air Acidification; EI: Eutrophication; HTI: Human toxicity; ATI: aquatic ecotoxicity and TTI: terrestrial ecotoxicity. LDPE: low density polyethylene; PE: polyethylene; PS: polystyrene.

	Biomass Inciner.	LDPE Inciner.	PE Inciner.	PS Inciner.	STEEL Inciner.	Biomass Landfill	LDPE Landfill	PE Landfill	PS Landfill	STEEL Landfill	Biomass Compost	categories
air emissions												
NH_3	8.2E–08	1.7E–07	1.5E–07	8.3E–08	3.1E–07	***9.8E–06***	5.4E–09	4.7E–09	6.4E–09	1.8E–11	4.0E–08	AI
CO_2	***7.8E+01***	***2.1E+01***	***1.8E+01***	***9.3E+00***	5.6E–01	***4.1E+01***	8.7E–01	7.6E–01	3.8E–01	1.8E–01	–3.7E–01	CCI
C_xH_y	0.0	7.3E–04	6.3E–04	3.1E–04	***2.5E–03***	6.9E–05	6.1E–04	5.3E–04	2.6E–04	***1.2E–03***	–3.4E–03	POI
Cu	4.4E–05	0.0	0.0	0.0	0.0	1.1E–07	0.0	0.0	0.0	0.0	7.6E–09	HTI, TTI
CH_4	0.0	2.9E–04	2.5E–04	1.2E–04	1.0E–03	***1.5E+01***	9.8E–02	8.6E–02	4.3E–02	2.2E–04	–2.0E–03	CCI, POI
NO_x	4.0E–03	4.2E–03	3.6E–03	1.9E–03	***9.5E–03***	4.4E–03	1.3E–03	1.2E–03	5.8E–04	2.6E–03	–6.1E–03	EI
N_2O	***2.2E–04***	2.2E–05	1.9E–05	2.5E–05	9.4E–06	1.1E–04	2.7E–06	2.3E–06	1.2E–06	5.0E–06	–7.5E–05	CCI
Cd	***1.5E–06***	6.7E–07	5.8E–07	***1.1E–06***	5.7E–09	6.5E–08	7.7E–09	6.7E–09	5.1E–09	2.5E–09	2.9E–09	ATI, HTI, TTI
Hg	0.0	***1.5E–05***	***1.3E–05***	2.0E–07	4.9E–09	0.0	1.5E–06	1.3E–06	1.6E–08	2.1E–10	2.9E–09	HTI, TTI
Pb	***1.7E–05***	***1.0E–05***	***9.0E–06***	1.1E–06	3.4E–08	3.3E–09	7.8E–09	6.8E–09	3.0E–09	1.3E–08	7.7E–08	HTI, TTI
Ni	***8.5E–07***	5.6E–08	4.8E–08	1.9E–08	2.9E–07	0.0	4.6E–08	4.0E–08	2.0E–08	8.8E–08	5.5E–08	HTI, TTI
Zn	7.1E–05	9.2E–05	8.0E–05	***1.1E–04***	4.3E–06	3.8E–07	1.3E–06	1.1E–06	5.5E–07	2.2E–06	1.4E–07	HTI, TTI
Water emissions												
NH_4	1.3E–05	3.5E–05	3.1E–05	1.3E–05	1.2E–05	1.7E–01	9.4E–05	8.2E–05	***1.5E–04***	4.7E–06	–6.0E–06	EI
Cd	1.0E–07	8.8E–06	7.6E–06	6.0E–06	1.3E–05	4.2E–06	***1.3E–05***	***1.2E–05***	9.5E–06	***2.6E–05***	1.3E–09	ATI
Cu	3.1E–05	1.6E–04	1.E–04	3.0E–05	5.9E–04	5.5E–05	***3.0E–04***	***2.6E–04***	5.1E–05	***1.2E–03***	1.1E–07	ATI
Pb	6.3E–07	***1.6E–04***	***1.4E–04***	6.7E–06	2.5E–05	3.7E–07	1.3E–05	1.1E–05	5.6E–07	5.0E–05	1.2E–07	ATI
Hg	0.0E+00	3.8E–05	3.3E–05	3.9E–07	1.8E–10	0.0	***7.9E–05***	***6.9E–05***	8.5E–07	2.7E–11	1.8E–10	ATI
Zn	1.9E–06	2.6E–03	2.2E–03	1.2E–03	9.1E–04	3.3E–04	***4.1E–03***	***3.6E–03***	2.0E–03	1.8E–03	2.3E–07	ATI

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