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Long term plant biomonitoring in the vicinity of waste incinerators in The Netherlands

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HIGHLIGHTS

- Burning of waste can result in the emission of potentially toxic compounds.
- Biomonitoring can be used to monitor the impact of emissions on agricultural crops.
- Heavy metals, PAHs and dioxins/PCBs levels were similar to background levels.
- The fluoride standard for cattle feed was sometimes exceeded in grass samples.
- The results have contributed to a better relationship between stakeholders.

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ABSTRACT

Since the mid-nineties new waste incineration plants have come into operation in the Netherlands. Burning of waste can result in the emission of potentially toxic compounds. Although the incineration plants must comply with strict conditions concerning emission control, public concern on the possible impact on human health and the environment still exists. Multiple year (2004–2013) biomonitoring programs were set up around three waste incinerators for early detection of possible effects of stack emissions on the quality of crops and agricultural products. The results showed that the emissions did not affect the quality of crops and cow milk. Concentrations of heavy metals, PAHs and dioxins/PCBs were generally similar to background levels and did not exceed standards for maximum allowable concentrations in foodstuffs (e.g. vegetables and cow milk). Some exceedances of the fluoride standard for cattle feed were found almost every year in the maximum deposition areas of two incinerators. Biomonitoring with leafy vegetables can be used to monitor the real impact of these emissions on agricultural crops and to communicate with all stakeholders.

1. Introduction

Since the mid-nineties new waste incineration plants have come into operation in various agricultural regions in the Netherlands to accommodate the increasing amount of wastes produced. Burning of municipal solid waste can result in the emission of potentially toxic compounds including heavy metals and organics such as dioxins and polychlorinated aromatic hydrocarbons (Hutton et al., 1988; Bache et al., 1991; Schuhmacher et al., 1998; Loppi et al., 2000). Emissions and aerial dispersion of these compounds depend on waste composition, design of the waste incineration plant, operating conditions during combustion, emission control, stack height and prevailing weather conditions (Bache et al., 1991). The incineration plants in this study comply with strict conditions concerning emission control, and state-of-the-art technologies are used to remove gaseous components and fly ash. However, there was, and still is great deal of public concern about the possible impact of the emissions on human health, well-being and the environment. These include serious concerns about the possible effects on the quality of their crops grown in the direct vicinity of incineration plants. In order to meet these concerns, biomonitoring programs were set up in the direct vicinity of incineration plants to detect possible effects on agricultural crops and products. Furthermore, arrangements were made for financial compensation should such effects occur.

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Biomonitoring with plants is a technique to indicate effects of ambient phytotoxic compounds (Mannig and Feder, 1980; Tonneijck et al., 2002; De Temmerman et al., 2004). Biomonitoring is performed with bioindicator and accumulator plants. Bioindicators are sensitive plant species showing visible symptoms such as necrosis, chlorosis, abortion of flowers or fruits, or growth reduction. Accumulators are generally less sensitive than bioindicators, but accumulate gases and particles in or onto their leaves without showing visible effects, which can be measured and analysed. Gases are usually taken up into the leaves and particulates are accumulated on the leaf surface, while lipophilic organic substances are primarily accumulated in the waxy layers of plant tissues (Falla et al., 2000; Garrec and Van Haluwyn, 2002). Biomonitoring can be used to monitor spatial and temporal distributions of environmental effects around emitters of air pollutants (Klumpp et al., 2002; Ernst, 2003; Weiss et al., 2003), or can be used as an early warning system (Keddy, 1991).

This study describes the results of multiple year (2004–2013) monitoring programs around three waste incinerators in The Netherlands. The aim of these programs was the early detection of possible effects of stack emissions on the quality of crops and agricultural products. These programs focus on components mainly emitted through the flue gases: the heavy metals cadmium (Cd) and mercury (Hg), polycyclic aromatic hydrocarbons (PAHs), dioxins (PCDD/PCDF) or dioxin-like polychlorinated biphenyls (PCBs) and fluorides (HF).

Depending on the chemical composition and amount of the collected waste, various heavy metals are emitted during the incineration process (Morselli et al., 1993). Metals like Cd and Hg are not fully retained in the slag or captured in the electrostatic filter, but are emitted as gas with other flue gases (Morselli et al., 1993). Therefore Cd and Hg are relevant components to monitor around waste incinerators. Gaseous Hg is spread over large distances, and above-ground plant organs absorb gaseous Hg (Stoop et al., 1992). When fume temperatures decrease, Cd is adsorbed by suspended particles and spread through the air and can be taken up by plants via the stomata. Cd is very mobile and can be easily transported throughout the plant, and eventually be stored in different plant parts such as roots, stems and seeds (Stoop and Rennen, 1991).

During incineration, polycyclic aromatic hydrocarbons (PAHs) are released by the incomplete combustion of organic materials in the waste stream. The ratio between the various hydrocarbons depends largely on the conditions during the combustion process. Especially high molecular PAHs have a wide range of toxicological effects on human health, including cancer. Plants can take up PAHs from the air, which to a very limited extent, can then be transported to other plant organs. Elevated levels in plant shoots are generally the result of leaf absorption (Debus et al., 1989; Franzaring, 1995). The major uptake routes are active uptake of gaseous PAHs through the stomata and the passive diffusion through the cuticle. Plant species with a high lipid content, wide, curled leaves and a surface structure favourable for uptake (thick wax layer) accumulate PAHs relatively easily. An example of such a plant is kale, in Germany frequently used as monitoring plant in routine environmental research (Radermacher and Rudolph, 1994; VDI, 1999).

Dioxins have no technical application and are therefore not deliberately manufactured. Dioxins and dioxin-like PCBs originate from a variety of combustion processes, including waste incineration. The residence time of individual components in the air depends on their physical form. Depending on material properties and temperature, dioxins and dioxin-like PCBs occur in the gas phase or are adsorbed to airborne particles. In combination with the meteorological conditions this determines the deposition area (Liem et al., 1993). Dioxins have the ability to accumulate in body fat. Livestock that consume contaminated feed, accumulate dioxins in fatty tissue and milk fat which becomes part of the food chain. Fürst et al. (1992) estimated that up to 90% of human exposure to dioxins and dioxin-like PCBs results from the consumption of food, mainly animal origin. The other 10% comes from inhalation and ingestion of ambient particles. Exposure to dioxins and dioxin-like PCBs can result in a wide range of toxicological effects on human health, including cancer and disturbance of the reproductive and immune system (SANCO, 2001).

In general fluoride levels in grass follow a seasonal pattern, with higher levels in autumn and winter and lower levels in the summer. Dilution of accumulated fluoride in plant tissue with higher growth rates and surface roughness are important factors for this seasonal fluctuation (Van der Eerden, 1991). Adverse fluoride effects can occur in livestock (fluorosis: damage to bones and teeth) by consuming plants with accumulated fluorides. Humans are less sensitive to fluorides; effects on human health as a result of ambient fluoride are negligible (Mennen et al., 2010) and fluoride is even intentionally added to drinking water and toothpaste.

The aim of these programs was to assess the effects of potentially toxic components on the quality of crops and agricultural products in the vicinity of waste incinerators. In addition, a qualitative assessment was made of the values of these biomonitoring programs for farmers, stakeholders and waste treatment companies.

2. Methodology

A biomonitoring program was set up around waste incineration plants nearby Alkmaar (Incinerator 1; 52°36′35.04″N/4°45′44.57″E) and Wijster (Incinerator 2, 52°47′25.62″N/6°30′49.42″E), each with a capacity of approximately 800–1.000 kiloton annual and a stack height of 80 m. A similar program was started in 2010 around the incinerator nearby Harlingen (Incinerator 3, 53°11′31.11″N/5°25′47.41″E) with a capacity of approximately 250 kiloton annual and a stack height of 40 m. The three incinerators were chosen for the state-of-the-art technologies they use. Together they process about 30% of the total annually waste incinerated with energy recovery in The Netherlands (Eurostat, 2010). A network of five sampling points was set up in the agricultural areas around each incinerator. The program was performed in the same way at each location. A general dispersion model (STACKS) was used to predict the distance where the plume would reach the ground under the prevailing wind direction (southwest). Based on these calculations the locations around Incinerator 1 and 2 were placed at a distance of 3–4 km and around Incinerator 3 at 1.5–2 km because of the lower stack height. In each network one location was located where the deposition was considered maximal, northeast of the installations (maximum deposition area). Three other locations were situated in opposite wind directions (SE, SW and NW). A fifth location was situated at a larger distance (10–12 km) outside the immediate influence of the stack gases in order to monitor the regional background concentrations (reference location). Each sampling location was first provided with an anti-rooting plastic to suppress weed growth and prevent contamination of the plants with soil particulates from the immediate vicinity. A 1 m high fence and windscreen was set up to protect the plants against rabbit herbivory and wind damage.

Spinach (*Spinacia oleracea* L.) and kale (*Brassica oleracea* L.) were used as accumulator crops because of their high growth rate, large leaf area and growing season. Both species have been commonly used as accumulator crops (Franzaring, 1995; De Temmerman and Hoenig, 2004). Depending on the time of year spinach and kale were used to monitor the accumulation of Cd, Hg and PAHs. At each sampling point plants were cultivated in 50 dm^3 containers with standard soil ('Lentse' soil No. 3, Horticoop, Bleiswijk, NL) with an automatic water supply (adopted from Posthumus, 1982). Spinach was harvested every four weeks in five consecutive exposure periods between April and August (Week 18, 22, 26, 30 and 34). Kale leaves were harvested at 8 week intervals during autumn and winter (Week 42, 50 and 6 of the next calendar year). Per sampling site all available leaf material was harvested, thoroughly mixed and dried at 40 °C for 48 h and subsequently ground to 1 mm and stored in plastic sampling containers. After extraction of the elements with concentrated nitric acid in a microwave concentrations of Cd and Hg were determined with Inductively coupled plasma mass spectrometry (ICP-MS), adopted from NEN-EN-ISO 17294 (2004). Concentrations of PAHs (16 EPA) were determined with gas chromatography/low resolution mass spectrometry (GC-LRMS) after extraction of the samples with toluol for 8 h and clean-up of the extract on a silica-gel column (adopted from VDI 3874, 2006).

Cow milk was sampled at two dairy farms (4 samples per year) in the vicinity of each incinerator to determine the concentrations of dioxins (PCDD/PCDF) and dioxin-like PCBs. Farms were selected where the cattle had mainly grazed in the maximal deposition area, or acquired part of their forage from that location. Samples were taken in week 22 and 38. The potential exposure of grazing lifestock was the highest. A one litre milk sample was taken from the storage tank (4 °C) and stored in a glass container and kept in cool storage during transport to the laboratory. Each sample was centrifuged and the upper layer (dry cream) was collected in a beaker with anhydrous sodium sulphate. After adding 150 mL of pentane, the extract was collected by decanting over a filter in a funnel and collected. The extraction was repeated two times. The sample was spiked with 13C-labeled standards (dioxins, furans, non-ortho PCBs, mono-ortho and non-dioxin-like PCBs). After drying overnight at 40 °C, the fat was weighted and cleaned using a Powerprep system. From the 210 different dioxin congeners, identification and quantification of the 17 most relevant dioxins and 12 dioxin-like PCBs was performed with gas chromatography/high resolution mass spectrometry (GC/HRMS), adopted from Tuinstra et al. (1994) and Hoogenboom et al. (2007).

The relative toxicity of dioxins and dioxin-like congeners was compared to the most toxic substance 2,3,7,8-TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin), the reference congener, and a toxic equivalency factor (TEF) was assigned. A toxic equivalency (TEQ) level was calculated by multiplying the actual level of each dioxin and dioxin-like compound by its corresponding TEF and then summing the results (Van den Berg et al., 2006).

Fluoride concentrations were measured in field-grown pasture grass. In the vicinity of each sampling point grass from a sufficiently large and homogeneous pasture was sampled at four-weeks intervals (13 samples per year). The grass was cut just above the ground at 16 points in a grid of 9×9 m. The grass was mixed and dried at 105 °C for 48 h and subsequently ground to 0.5 mm and stored in plastic sampling containers. Fluoride concentrations were determined by ashing 0.5 g of grass for 2 h at 520 °C. The ash was dissolved in NaOH and water. Fluoride was distilled from the solution with sulphuric acid at 170 °C, condensed and mixed with a colouring agent followed by colorimetric measurement at 620 nm (adopted from Weinstein et al., 1972; CBLB, 2011).

3. Results and discussion

3.1. Effects on the quality of crops and agricultural products

To prevent the influence of pollutant uptake from the soil, spinach and kale plants were cultivated in containers with unpolluted standard soil. Consequently, pollutants in above-ground plant organs are considered to be the result of aerial uptake. Indicative background levels of cadmium, mercury and PAHs in spinach and kale were calculated from the concentrations measured at all three reference locations over the last five years (moving five-year average and standard deviation). With these reference data, longer-term trends can be highlighted and the average levels measured in the direct surroundings of each incinerator can be distinguished from the background level for the Netherlands. The range in the moving five-year average indicates the variation in time and whether there is an upward or downward trend. The same approach was used for the background level of fluorides in grass, and included the results of three additional sampling points in non-polluted areas in The Netherlands. The background level of dioxins and dioxins-like PCBs was based on an inventory of the Dutch Institute of Food Safety over the period 2001–2010 (Schoss et al., in prep.).

3.1.1. Heavy metals

The multiple year results from the biomonitoring programs in this study showed that individual Cd levels in spinach and kale exhibited some variation between sampling points and throughout the season, including the reference sampling point. Part of the variation can be explained by differences in plant growth, diluting the accumulated metals. This variation explains the bandwidth of the background level. The annual mean Cd levels in spinach from 2004 to 2013 from the four sampling points in the direct vicinity of each incinerator were within the range of the background level (Fig. 1, left). The order of magnitude of the Cd levels was similar for the three incinerators, despite the differences in incineration capacity and emission flows. The capacity of incinerators 1 and 2 is three to four times higher than for incinerator 3. The 2010 average levels around incinerator 3 refer to the background level in that year because the incinerator was still under construction, and only became operational in the beginning of 2011. The higher levels in 2010 measured around incinerators 1 and 2 are therefore not likely the result of higher emissions, but higher background concentrations. The Cd concentrations in kale were lower than those in spinach, and were within the range of the background level (Fig. 1, right). Higher levels occurred around incinerator 1 and 2 only in 2006. They resulted from higher Cd levels at all sampling points including the reference points in autumn (October) and early winter (December). Thus, it is unlikely that the emission of the incinerators was responsible for these higher levels in kale. The maximum acceptable Cd level for leaf vegetables (200 $\mu g\ kg^{-1}$ fresh weight) to protect public health (EC, 2008) was not exceeded.

Hg levels in both spinach and kale were relatively low throughout the whole monitoring period (Fig. 2), even though Hg is one of the few heavy metals mainly emitted as gaseous component by waste incinerators. Vapour phase Hg is mainly due to the incineration of discarded batteries (Bergström, 1986), and domestic solid waste in The Netherlands contains only 0.03% discarded batteries (Ministry of Infrastructure and Environment, 2013) due to a high degree of battery recycling. This could well be an explanation for the relatively low Hg levels found in spinach and kale. Furthermore gaseous mercury is distributed over a larger area than particle-bound cadmium. These findings are consistent with low Hg concentrations found in lichens around an incinerator in central Italy (Loppi et al., 2000). No maximum acceptable Hg level for leaf vegetables has been defined.

3.1.2. PAHs

Regarding heavy metals, individual PAH levels in spinach and kale were variable between sampling points and throughout the season. Variation in PAH levels also occurred at the reference sampling point, which explains the bandwidth of the background level. PAH levels in crops are correlated to seasonal fluctuations

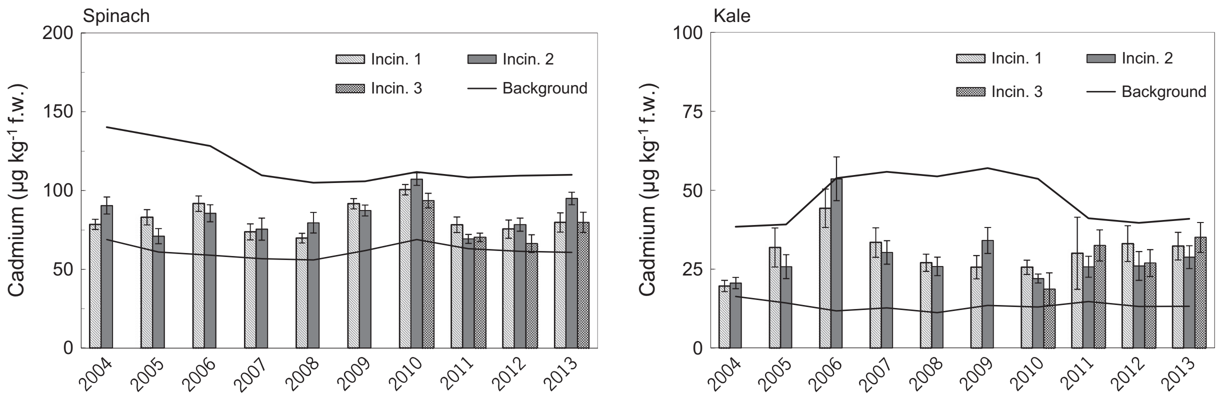

Fig. 1. Mean (±SE) cadmium levels (µg kg^{-1} f.w.) in spinach (left) and kale (right) exposed to ambient air in the vicinity of three waste incinerators from 2004 till 2013. The solid lines indicate the range for the background level. The maximum acceptable Cd concentration in leaf vegetables to protect public health is 200 µg kg^{-1} f.w. (EC, 2008).

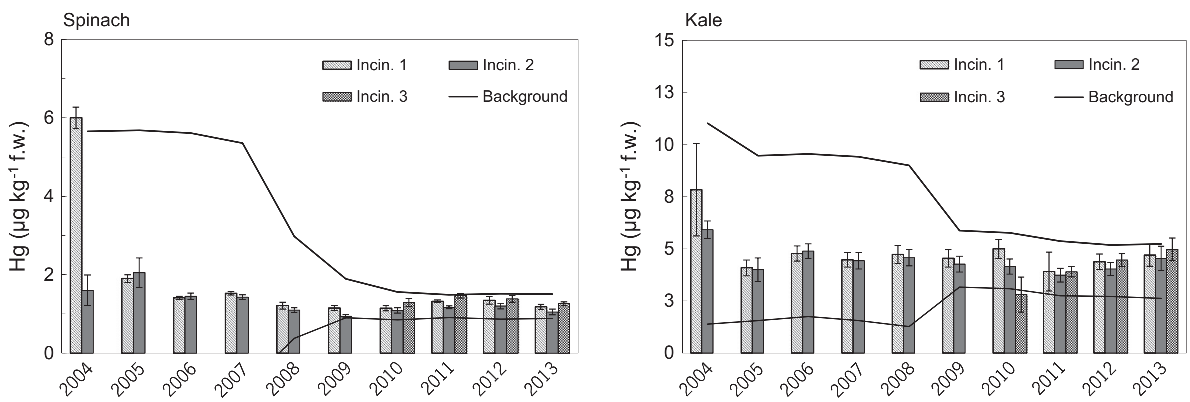

Fig. 2. Mean (±SE) Hg levels (µg kg^{-1} f.w.) in spinach (left) and kale (right) exposed to ambient air in the vicinity of three waste incinerators from 2004 till 2013. The solid lines indicate the range for the background level.

corresponding to the fluctuations in the local air temperature and particle concentration. During periods with lower temperatures PAH emissions increase due to heating and combustion processes. At the same time, the degradation of atmospheric PAHs is relatively low due to lower UV radiation levels in winter compared to the summer period. Decreasing temperatures also lead to increasing condensation of PAHs on airborne particles (Franzaring, 1995; Sucharova and Hola, 2014).

From 2004 to 2013 the PAH levels in spinach and kale, averaged annually for the four sampling points in the direct vicinity of each incinerator, were generally within the range of the background level (Fig. 3). In the summer of 2004 the PAH levels in spinach around incinerators 1 and 2 were higher than the upper limit of the background level. No unexpected deviations in the emission pattern were detected and higher levels occurred at all sampling points, including the two reference points. Therefore, it is unlikely that the emission of the incinerators was responsible for these higher levels. PAH levels in spinach around incinerator 3 were slightly lower than levels around incinerators 1 and 2, which could be due to its lower capacity. However, these differences in kale

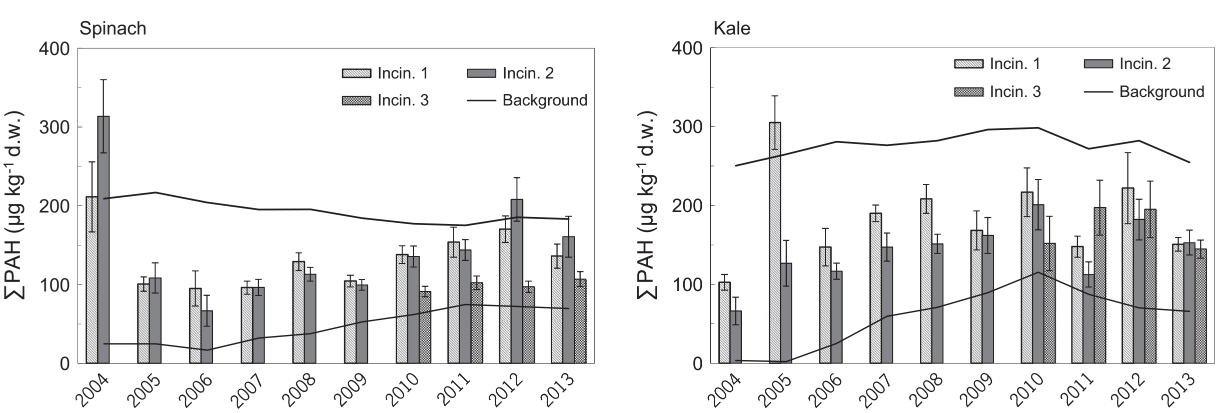

Fig. 3. Mean (±SE) PAH levels (µg kg^{-1} d.w.) in spinach (left) and kale (right) exposed to ambient air in the vicinity of three waste incinerators between 2001 and 2011. The solid lines indicates the range for the background level.

were not detected. PAH levels in kale around incinerator 1 in 2005 were above background levels and were also higher compared to incinerator 2 with a comparable capacity. The higher PAH levels in kale in the winter were the result of high levels of individual PAHs, benzo(a)anthracene, chrysene and benzo(b)fluoranthene. Other individual PAHs (13) were below the detection limit. There was no a statistically significant relationship between the higher PAH levels and the frequency of wind (hours) in the direction of the incinerators towards the sampling points.

3.1.3. Dioxins

The levels of dioxins (mean of 4 samples per year) in milk from the dairy farms in the immediate vicinity of the incinerators are comparable to the average background level for The Netherlands, i.e. 0.34 pg TEQ g^{-1} fat. The dioxin concentrations were relatively constant over time. The dioxin-like PCB concentrations showed a slight tendency to decrease over the years, which is in line with the results from the national survey from 2001 to 2010 (Schoss et al., in prep.). Results from a European survey showed that average dioxins and dioxin-like PCB levels in milk were about twice as high as the concentrations found in this study (EFSA, 2010). Dioxins and PCB levels do not appear to be related to emissions from the incinerators (Fig. 4). The levels of dioxins and the sum of dioxins and PCBs remained well below the maximum permissible level for milk and milk products of 2.5 and 5.5 pg TEQ g^{-1} fat respectively (EC, 2011). The results show that there is no potential risk with respect to the consumer quality of the examined milk.

3.1.4. Fluoride

Fluoride levels in pasture grass in the vicinity of the incinerators were generally at background levels, and followed the usual seasonal patterns. However, the annual average fluoride concentrations in grass in the immediate vicinity of incinerator 1 were higher than the background levels for several years (Fig. 5). Particularly in the winter period, levels were higher than expected based on the seasonal background level. The strictest standard for feed for young cattle (25 μg g^{-1} DW) set by the Dutch Health Council (Gezondheidsraad, 1990) was exceeded in most years (the European standard for feed for cattle, sheep and goats in lactation is 30 μg g^{-1} DW; EC, 2002). Fluoride levels in the summer were relatively low. In 2004–2007, 2009 and 2012 a significant relationship ($p < 0.05$) was found between the fluoride concentration and the frequency of wind (hours) from the incinerators towards the sampling points. Although a causal relationship was not proven and the correlation coefficients were low, a contribution of the emissions to the fluoride levels found could not be completely excluded. For these years, no increased concentrations were found in the continuous stack-measurements of HCl, a parameter with an emission pattern expected to be similar to that of fluorides. In

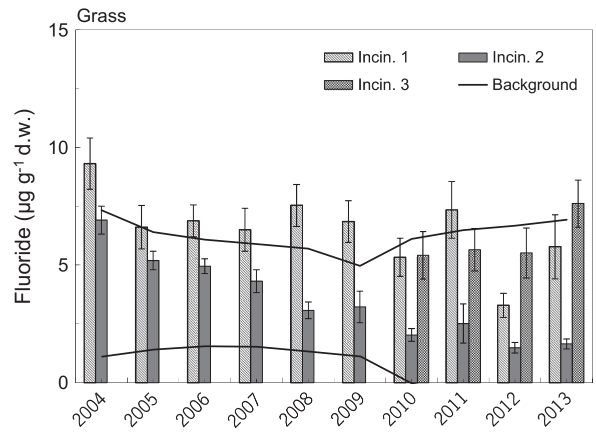

Fig. 5. Fluoride (μg g^{-1} d.w.) in pasture grass harvested in the vicinity of three waste incinerators. The maximum acceptable concentration in feed for young cattle is 25 μg g^{-1} dw (Gezondheidsraad, 1990).

2013, in the vicinity of incinerator 3 a similar pattern was found with higher fluoride levels in winter and several exceedences of the maximum standard for feed. From 2004 to 2013 the fluoride levels in grass around incinerator 2 were within the range of the background level, showing a decreasing trend. With regard to the risk to livestock, the fluoride levels in grass were of little significance.

Incinerators 1 and 3 are located relatively close to the coast. The contribution of sea salt to the fluoride concentration in the air could be a possible explanation of the higher fluoride levels. Sea water contains about 33 g l^{-1} of minerals, including 1.3 mg l^{-1} fluoride (CRC, 1989). The concentration of salt in the air in the coastal areas is approx. 5 μg m^{-3} (Hoogerbrugge et al., 2011). This means that the content of fluoride in the air as a result of the emission from the sea is about 0.0002 μg m^{-3}. This contribution is negligible compared to a background concentration of approx. 0.05 μg m^{-3} and no other mechanisms for fluoride emissions from seawater are known.

3.2. Stakeholders response to the monitoring programs

3.2.1. Farmers and residents living nearby the installations

Emissions from waste incineration plants contain components that are potentially toxic for humans, plants and animals. Major concerns often exist concerning the group of persistent organic compounds (‘dioxins’). Therefore, plans for the construction of new installations meet resistance from local residents and environmental groups due to the fear of potential adverse health effects,

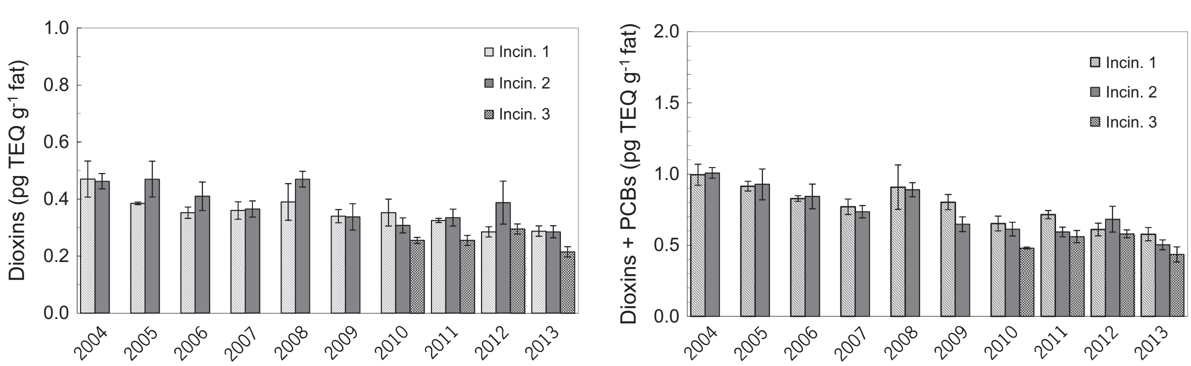

Fig. 4. Levels of dioxins (left) and dioxins + dioxins-like PCBs (right) in milk from dairy cattle in the vicinity of three waste incinerators (pg TEQ g^{-1} fat). The maximum acceptable concentration for dioxins in milk en dairy products is 2.5 pg TEQ g^{-1} fat. For dioxins + dioxins-like PCBs the standard is 5.5 pg TEQ g^{-1} fat (EC, 2011).

environmental contamination and the association of these facilities with odours, noise, visual intrusion, and the reduction in value of land and property. Major resistance also occurred in this case, when de plans for building these facilities became public. Whether the fear for health effects was justified cannot be answered with certainty. The results of various studies on the causal relationship between human health effects (reproduction, cancer, respiratory and heavy metals in the body) and exposure to emissions from incinerators are inconclusive (Hu and Shy, 2001; DEFRA, 2004). However, in general the (planned) presence of a incineration plant is perceived to be a potential risk by local residents (risk perception). Lima (1996) showed that risk perception can have an effect on the quality of life (health, environment, income) and mental well-being by introducing a dimension of danger in the residential environment. Furthermore, there are continuous reminders (noise, smell, smoke) of the closeness of the installation which requires extra effort (stress responses) to minimize the risks and adapt to this permanent threat (Lima, 2004).

Although it was not the primary aim of this research, the predominantly positive results (no effect) from the biomonitoring programs during the past decade have contributed to less uncertainty concerning health effects by neighbouring farmers and residents. The method of measuring ambient pollutants in plants grown at ground level, is probably closer to the real world of farmers and residents than the (legal mandatory) stack measurements, and therefore more convincing. The farmer's representation in the advisory committees of these programs also made it possible to discuss points of criticism and concerns. In the annual advisory committee meetings, an open communication existed on the program results and developments in the agricultural sector. In return, positive developments in the position and functioning of the waste incinerator took place. Confidence and trust (good-neighbour ship) were built up over time, resulting in present absence of farmer's resistance against the waste incineration installations.

3.2.2. Waste incinerating companies

Poor performance and incidents with (unintended) emissions of flue gases from mainly older incineration plants made waste incineration controversial in the past. Nowadays, most of the old incinerators are closed and new installations have come into operation. The companies involved are striving for the most sustainable waste processing with the best possible protection of the environment. Outside of formal permission or regulatory processes, a good relationship with the farmers and residents living nearby the installations have become increasingly important. Differences in perception between company and residents in the past often resulted in time and money consuming lawsuits and negative imaging in the press. In order to meet the public concerns, the biomonitoring programs were set up to detect possible effects on crops in the vicinity of the incineration plants indicating their potential effects on the environment. These programs and the proven absence of significant negative effects have contributed to achieving the objectives of sustainability and social responsibility of the companies involved.

3.3. Future developments

It is becoming increasingly more important to consumers and retail businesses that agricultural products are produced safely and hygienically. Due to this development, more and more farmers are working with food safety certification systems (GLOBALGAP). Certification aims to ensure the food safety during cultivation, harvest, transport and storage of crops for processing. Biomonitoring can contribute to the quality assurance of cultivated crops and products by demonstrating the absence of important ambient pollutants such as heavy metals, polycyclic aromatic hydrocarbons and dioxins.

Due to overcapacity, commercially-operated Dutch incinerators are importing municipal waste from other countries, mainly from the UK, Germany and Italy (approx. 300.000 ton in 2012) of which the exact composition is not always known. For the coming years it is expected that this import will further increase to 2–3 million tons per year, approx. 25–30% of the total incinerating capacity in The Netherlands (Rabo, 2012). By using state-of-the-art technologies and following good waste management practices, impacts on the environment can be minimized. However, from the point of view of the local community, this development could also become a strong argument for implementing new or continuing existing biomonitoring programs.

4. Conclusions

This study shows that leafy vegetables can be used for monitoring the impact of atmospheric deposition, which is consistent with previous research (Franzaring, 1995; VDI 3957/3, 2000; De Temmerman and Hoenig, 2004). The multiple year (2004–2013) results of monitoring in the vicinity of waste incinerators showed that the emissions did not affect the quality of crops and cow milk. Concentrations of heavy metals, PAHs and dioxins/PCBs were generally similar to background levels and did not exceed standards for maximum allowable concentrations in foodstuffs (e.g. vegetables and cow milk). The results also show that there is no potential risk with respect to human consumption quality of the investigated crops and products in the vicinity of the incinerators. Some exceedances of the fluoride standard for cattle feed were found almost every year in the maximum deposition area of the incinerators 1 and 3. A contribution of the emissions to these levels found could not be completely excluded. However, in absolute terms these levels are of minor significance with respect to the risk to livestock and have been accepted as such by the farmers.

Biomonitoring can be used to monitor the impact of ambient emissions from incinerator facilities on agricultural crops and products. The positive results (no effect) in combination with the open communication between stakeholders have also contributed to less uncertainty concerning potential health risks and have contributed to a better relationship between the farmers, residents and the companies involved. Future developments regarding increasing waste import from other countries is a strong argument for the implementation of new or the continuing of existing biomonitoring programs in the vicinity of incinerators.

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