Science of the Total Environment 595 (2017) 515–520

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Proximity to agricultural fields as proxy for environmental exposure to pesticides among children: The PIAMA birth cohort

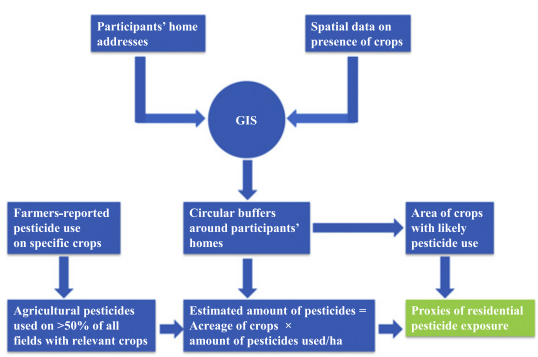
Joseph S. Bukalasa [a,*], Bert Brunekreef [a,b], Maartje Brouwer [a], Roel Vermeulen [a,b], Johan C. de Jongste [c], Lenie van Rossem [b], Judith M. Vonk [d], Alet Wijga [e], Anke Huss [a], Ulrike Gehring [a]

[a] Institute for Risk Assessment Sciences, Utrecht University, Utrecht, The Netherlands
[b] Julius Center for Health Sciences and Primary Care, University Medical Center Utrecht, Utrecht, Netherlands
[c] Department of Pediatrics, Division of Respiratory Medicine, Erasmus University Medical Center/Sophia Children's Hospital, Rotterdam, The Netherlands
[d] Department of Epidemiology, Groningen Research Institute for Asthma and COPD (GRIAC), University of Groningen, University Medical Center Groningen, Groningen, The Netherlands
[e] Center for Nutrition, Prevention and Health Services, National Institute for Public Health and the Environment, Bilthoven, The Netherlands

HIGHLIGHTS

- Proximity of home address to fields likely treated with pesticides was assessed.
- Proximity to likely treated fields was used as proxy for pesticides exposure.
- Acreage of fields was combined with farmer-reported pesticide use on those fields.
- Few participants lived within 100 m of fields likely treated with pesticides.
- About two-thirds lived within 1000 m of likely treated fields.

GRAPHICAL ABSTRACT



Assessment of residential proximity to crop fields likely treated with agricultural pesticides as proxies for environmental pesticide exposure - flow chart.

ARTICLE INFO

Article history:
Received 12 December 2016
Received in revised form 28 February 2017
Accepted 29 March 2017
Available online 7 April 2017

Editor: D. Barcelo

Keywords:
Birth cohort
Exposure
Agricultural pesticides
Geographical information system

ABSTRACT

Background: Agricultural pesticides are frequently used for crop protection. Residents living in close proximity to treated fields may be exposed to these pesticides. There is some indication that children living near agricultural fields have an increased risk of developing asthma and decreased lung function.
Objectives: The aim of this study was to assess the proximity of participants' homes to fields likely treated with pesticides as proxy for environmental exposure to agricultural pesticides among participants of a Dutch birth cohort study, and to combine acreage of fields with farmer-reported pesticide use.
Methods: Potential pesticide exposure at the home address at the time of the 14-year follow-up was estimated for 2291 participants of the Dutch PIAMA birth cohort study. We used spatial data on the presence of crops during the year 2012 to calculate the surface area of specific crops relevant for pesticide use in The Netherlands cultivated within 50, 100, 500 and 1000 m of the study homes. Farmer-reported pesticides use on specific crops from a national survey performed in 2012 was used to estimate the amount of all pesticides and pesticides with known irritant properties for the respiratory system applied within the aforementioned distances of the study homes.

* Corresponding author at: Institute for Risk Assessment Sciences, Division Environmental Epidemiology, Utrecht University, Netherlands.
E-mail addresses: j.s.bukulasa@uu.nl (J.S. Bukalasa), b.brunekreef@uu.nl (B. Brunekreef), M.Brouwer1@uu.nl (M. Brouwer), R.C.H.Vermeulen@uu.nl (R. Vermeulen), j.c.dejongste@erasmusmc.nl (J.C. de Jongste), L.vanRossem@umcutrecht.nl (L. van Rossem), j.m.vonk@umcg.nl (J.M. Vonk), alet.wijga@rivm.nl (A. Wijga), a.huss@uu.nl (A. Huss), u.gehring@uu.nl (U. Gehring).

http://dx.doi.org/10.1016/j.scitotenv.2017.03.269
0048-9697/© 2017 Elsevier B.V. All rights reserved.

Results: For 3%, 7%, 40%, and 65% of the homes, any relevant crops were present within 50, 100, 500 and 1000 m, respectively. Among these, the most frequent crops were corn, cereals, and potatoes. For almost the same percentages of homes, it was estimated that pesticides with known irritant properties for the respiratory system were potentially applied within these distances.

Conclusions: We observed that a small proportion of the study participants lived in close proximity (<50 or <100 m) to agricultural fields with crops relevant for pesticide use in The Netherlands. The percentage of study homes within 500 or 1000 m of agricultural fields with these crops was much larger.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

The Netherlands is well known for the production of a variety of crops, such as corn, fruits, vegetables, potatoes, floriculture, and flower bulbs. Pesticides are widely used in agriculture in order to increase production and prevent damage (Van Dijk et al., 1999). Residents living in close proximity to agricultural fields may be exposed to pesticides through primary spray drift or after application, e.g. through volatilization of pesticide residues from crops and soil or wind erosion of soil particles (Deziel et al., 2015; FOCUS Working Group, 2008). This was examined in a study conducted in The Netherlands, which included 12 bulb growers' (farmers') homes and 15 nonfarmers' houses located approximately 10–400 m from flower bulb fields, and found increased concentrations of pesticides in house dust samples of farmers and non-farmers (Hogenkamp et al., 2003). Similar increases were reported by studies conducted in California and Iowa in homes within 500 m and up to 1250 m from vegetables, corn and strawberry fields (Gunier et al., 2011; Harnly et al., 2009; Ward et al., 2006). Findings of the US studies may not be directly transferable to The Netherlands because of differences in agricultural pesticide application practices.

While it is true that most of the pesticides applied in modern agriculture are not persistent in the natural environment, they do tend to persist more in houses due to lack of degrading microorganisms, moisture and sunlight. This shows the importance of investigating exposure to agricultural pesticides among children, as pesticide exposure in homes has been associated with respiratory diseases among children (Lewis et al., 1994; Salameh et al., 2003; Schwartz et al., 2015; Xu et al., 2012).

There are several methods of assessing environmental exposure to agricultural pesticides: by collecting house dust samples or biological samples such as blood or urine. Such samples can be analysed for pesticide residues or their metabolites (Bouvier et al., 2005; Chevrier et al., 2014; Lewis et al., 1994). These direct methods of assessing environmental agricultural pesticides exposure, however, are time consuming and costly and therefore, not suitable for large-scale studies.

Environmental exposure to agricultural pesticides can also be assessed indirectly by combining spatial data on crop cultivation with information on the location of residential homes in a Geographic Information System (GIS). This method is suitable for efficiently assessing environmental exposure to pesticides in large population studies (Booth et al., 2015; Rappazzo et al., 2016). One of the limitations of this method is that is it does not provide information about the specific pesticides applied. In The Netherlands, spatial data on annual crop cultivation is available for recent years, but spatially resolved information on pesticide use is lacking. We addressed this problem in the present study by combining geographical information data on the presence of crops with likely pesticide use in The Netherlands with data on farmer-reported pesticide use on specific crops.

The aim of this study was to assess the proximity to fields likely treated with pesticides as proxy for environmental exposure to agricultural pesticides at the home addresses of the participants of the Dutch PIAMA cohort at the time of the 14-year follow-up. A second aim was to estimate average annual pesticide use on these fields using data on farmer-reported pesticide use.

2. Methodology

2.1. Study design and population

The PIAMA (Prevention and Incidence of Asthma and Mite Allergy) study is a prospective Dutch birth cohort study. The baseline study population consisted of 3963 participants from the northern, middle and western parts of The Netherlands. Participants were born in 1996 and 1997 (Wijga et al., 2014). The PIAMA study has been designed to study the influence of life style and environmental factors on the development of asthma and allergies in children. Questionnaires were administered to the parents during pregnancy, at the child's ages of 3 months and 1 year, and then annually until the age of 8 years. When the children were 11, 14, and 17 years old, both parents and children completed questionnaires (again).

Data on the presence of crops ('BRP gewaspercelen', Dutch Ministry of Interior and Kingdom Relations, 2013). and data on self-reported agricultural pesticide use, collected in a national survey among farmers (Statistics Netherlands (CBS), 2012), were available for the year 2012, when the participants were approximately 15 years old. Therefore, the residential address at the time of the 14-year questionnaire was used to assess participants' environmental agricultural pesticides exposure for the year 2012. A total of 2291 children, who participated in the 14-year follow-up and had geocoded residential addresses, were included in this study.

2.2. Environmental agricultural pesticide exposure assessment

Environmental exposure to agricultural pesticides was assessed using the participants' home addresses, geographic information system data on the presence of crops and survey data on specific pesticide use (Fig. 1). We assessed environmental exposure to agricultural pesticides in three different ways: 1) by the presence of any crops relevant for pesticide use in The Netherlands in circular buffers with radii of 50, 100, 500 and 1000 m around the children's homes; 2) by the presence of specific crops relevant for pesticide use in The Netherlands within these distances from the children's homes; 3) by estimating the amount of (specific) agricultural pesticides used within these buffers.

2.3. Presence of (specific) crops around the child's home address

We imported the x-y coordinates of the participants' home addresses at the time of the 14-year follow-up into a geographical information system using ArcGIS and combined them with the location of crop plots ('BRP gewaspercelen') of 2012 (National Georegistry, 2012). The BRP is a national vector data set of 69 different types of crops at an underlying scale of 1:10,000, with annually updated crop information. Next, for each home address, circular buffers with radii of 50, 100, 500 and 1000 m were created and intersected with the BRP dataset (Supplementary Fig. 1). These circular buffers were selected based on primary spray drift (likely relevant at 50 and 100 m primarily) and secondary transport processes (500 and 1000 m) from agricultural fields during and after application (Gunier et al., 2011; Hogenkamp et al., 2003; Simcox et al., 1995). For each of the selected crops (a list of all selected crops is presented in Supplementary Table 1), the total surface

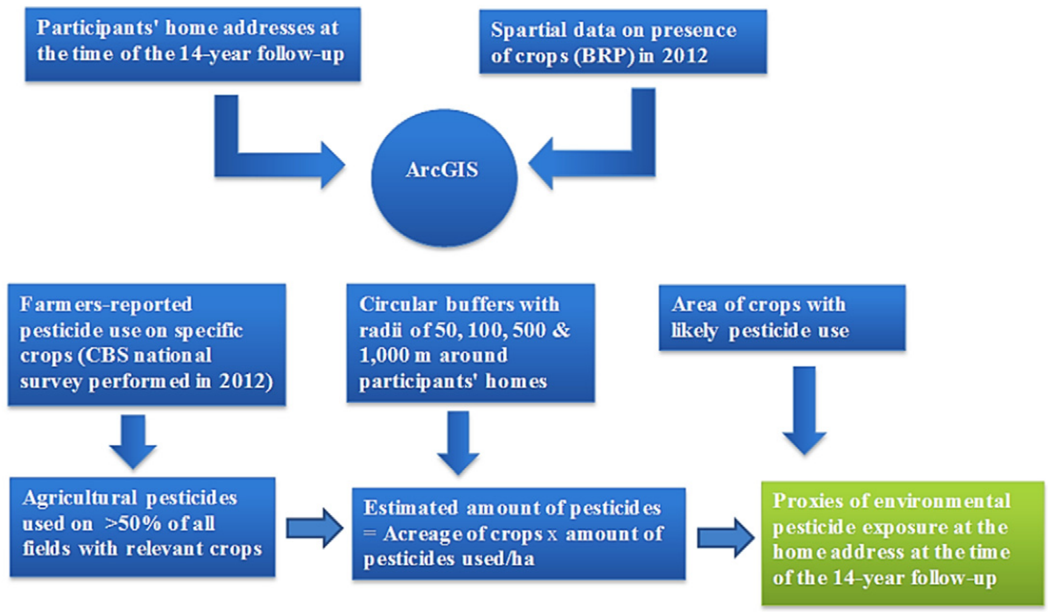


Fig. 1. Assessment of residential proximity to crop fields likely treated with agricultural pesticides as proxy for environmental exposure to pesticides - flow chart.

area within a specific distance around the homes was calculated. Furthermore, the selected crops were grouped into fruit, cereals, vegetables, commercial crops, floriculture/bulbs, corn, and potatoes (Supplementary Table 1).

2.4. Amount of agricultural pesticides used around children's homes

We used data from a survey of Statistics Netherlands (CBS) among farmers performed in 2012, which collected information on self-reported agricultural pesticide use for a number of crops (Statistics Netherlands (CBS), 2012). In that survey, farmers provided the amount (in kg) and the area treated, and CBS calculated the average dosage in kg/ha (among farmers who applied pesticides) and the overall average kg/ha (for the total crop area, including those not treated). For this survey, farmers were randomly selected and approximately 3000 farmers completed questionnaires on agricultural pesticide use on specific crops. The CBS dataset was then linked to the area of crops extracted from the BRP data as described in Supplementary Table 2. There were 191 unique agricultural pesticides listed in the 2012 CBS pesticides survey. We restricted our analysis to the 79 agricultural pesticides (herbicides, fungicides, growth regulators and insecticides), which were reported to be used in >50% of the agricultural fields for any of the selected crops that were present within 1000 m of the study participants' homes. We used the 50% cut point to ensure a reasonable probability of actual pesticide use on fields near participants' homes. For each of these agricultural pesticides, we estimated the total amount (in kg) applied in 2012 within 50, 100, 500 and 1000 m of the participants' home addresses by multiplying the acreage for a specific crop with the amount of specific agricultural pesticide used on this crop.

Agricultural pesticides that are known to be associated with respiratory endpoints were identified from the pesticides properties database (PPDB) and the pesticides manual (University of Hertfordshire, 2016). The PPDB has four categories: 1. yes, known to cause a problem; 2. no, known not to cause a problem; 3. possibly, status not identified; 4. no data found. We selected agricultural pesticides with known irritant properties for the respiratory system ($n = 25$).

2.5. Statistical analysis

For both the surface area cultivated with relevant crops and the estimated amounts of agricultural pesticides applied, the median, lower and upper quartiles, 90th and 95th percentiles, and maximum were calculated for the 50, 100, 500 and 1000 m buffers around children's homes. We calculated Spearman correlation coefficients between surface areas of specific crops and estimated amounts of individual agricultural pesticides applied, respectively, within the different buffers around children's homes. Heat maps were created to visualize these correlations.

We also created heat maps of the Spearman correlation coefficients between individual pesticides with known irritant properties for the respiratory system applied within 50, 100, 500 and 1000 m distance around children's homes and the surface area of specific selected crops present within these distances of the children's homes.

We also categorized areas of crops and estimated amounts of agricultural pesticides used (all pesticides and pesticides with known irritant properties for the respiratory system) and investigated the agreement (weighted kappa) between them for the 50, 100, 500 and 1000 m buffers around children's homes. We used tertiles of non-zero values and put all zero values in a baseline reference category. The purpose of this analysis was to provide a simplified presentation of our data in addition to the univariate statistics and Spearman correlation coefficients.

Statistical analyses were performed in SAS version 9.4 except for the correlation heat maps, which were produced with R 3.0.2 software package.

3. Results

Supplementary Fig. 2 shows a map of The Netherlands with the addresses of all PIAMA participants at the time of the 14-year follow up. The provinces of Friesland, Groningen, in the north of the country, and the provinces of Zuid-Holland and Utrecht, in the center and west of the county, are highlighted as these are the provinces were most of the study participants lived. Supplementary Figs. 3–9 shows parcels of land with cereals, corn, potatoes, vegetables, floriculture/bulbs, fruit trees, and commercial crops for the year 2012 together with the 14-year home addresses of the cohort participants for the provinces of Friesland, Groningen, Utrecht, and Zuid-Holland. The maps show that cereals, corn, potatoes, and commercial crops were more common in the provinces of Friesland and Groningen, and that vegetables, floriculture/bulbs and fruit trees were more present in the provinces of Utrecht and Zuid-Holland.

A total of 3%, 7%, 40% and 65% of the children's homes had any of the selected crops within 50, 100, 500 and 1000 m, respectively (Table 1). Corn, cereals, and potatoes were the most common crop groups found within these distances around the children's homes (Table 1).

Table 2 presents the distribution of the number of square meters for any selected crops and crop groups within 50, 100, 500 and 1000 m of the children's homes. The 95th percentiles of the cultivated areas were 1516 m^2, 214,430 m^2 and 1,148,806 m^2 (0.2, 21.4 and 114.8 ha) for the 100 m, 500 m and 1000 m buffers, respectively. Corn, potatoes and cereals occupied the largest surface areas within each of the analysed distances from the study homes.

One or more out of a set of 79 pesticides reported in the 2012 survey were estimated to be applied within 50, 100, 500, and 1000 m of 3%, 7%, 40%, and 64%, of the homes, respectively (Supplementary Table 3). These numbers were very similar for the subset of pesticides with known respiratory irritant properties (Supplementary Table 3). The small differences in percentages between all 79 pesticides and the 25 pesticides with known irritant properties for the respiratory system are due to the fact that pesticides like florasulam, mancozeb, terbuthylazine, and nicosulfuron, which are respiratory irritants, were applied on the most prevalent crops such as corn, potatoes and cereals.

Chlormequat, diquatdibromide, mancozeb, prosulfocarb, and terbuthylazine were the pesticides, estimated to be applied in the largest amounts within all buffers (Supplementary Table 3).

Heat maps of Spearman correlation coefficients of crop group-specific surface areas within 50, 100, 500 and 1000 m of the children's homes are shown in Supplementary Figs. 10–13. Correlations were high between cereals, potatoes, and commercial crops. We observed low to moderate correlations ($r_s < 0.7$) between the surface areas cultivated with vegetables and cereals, potatoes and commercial crops, and corn and cereals within 50, 100, 500 and 1000 m buffers (Supplementary Figs. 10–13).

Heat maps of Spearman correlation coefficients between the estimated amounts of all individual agricultural pesticides that were applied on the selected crops within 50, 100, 500, and 1000 m of the children's homes (56 and 72 different pesticides for the 50 and 100 m buffers, 79 different pesticides for the 500 and 1000 m buffers) are presented in Supplementary Figs. 14–17. Heat maps of Spearman correlations between the estimated amounts of individual agricultural pesticides with known irritant properties for the respiratory system applied on the selected crops are shown in Supplementary Figs. 18–21 for the 50, 100, 500, and 1000 m buffers (16 and 22 different pesticides applied within the 50 and 100 m buffer, respectively, 25 different pesticides applied within the 500 and 1000 m buffers). We observed moderate to high correlations ($r_s > 0.5$) between some of the individual agricultural pesticides with known irritant properties for the respiratory system. Most correlations, however, were weak. The moderate to high correlations ($r_s > 0.5$) include those between iodosulfuron methyl sodium and methosulfuron methyl, chlormequat and iodosulfuron methyl sodium, chlormequat and mesosulfuron methyl, terbuthylazine and florasulam, nicosulfuron and florasulam, lambda cyhalothrin and maneb, lambda cyhalothrin and asulam, kresoxim methyl and lambda cyhalothrin, kresoxim methyl and maneb, maneb and asulam, kresoxim methyl and asulam and nicosulfuron and terbuthylazine.

When we categorized surface areas cultivated with the selected crops and total estimated amounts of agricultural pesticides used, the agreement between crop surface area and amounts of pesticides was high (weighted kappa 0.8–0.9) for all specified distances from children's homes (Table 3 for pesticides with known irritant properties for the respiratory system and Supplementary Table 4 for all selected pesticides).

Table 1
Presence of crops (grouped) relevant for pesticide use in The Netherlands within of 50, 100, 500 and 1000 m of the home addresses of the PIAMA participants at the time of the 14-year follow up (N = 2291).

	Radius of circular buffer			
	50 m N (%)	100 m N (%)	500 m N (%)	1000 m N (%)
Any crops	70 (3.0)	170 (7.4)	926 (40.4)	1480 (64.6)
Orchard	2 (0.1)	5 (0.2)	57 (2.5)	118 (5.2)
Cereals	20 (0.9)	52 (2.3)	380 (16.6)	750 (32.7)
Vegetables	0 (0)	6 (0.3)	93 (4.1)	249 (10.9)
Commercial crops	6 (0.3)	17 (0.7)	206 (9)	468 (20.4)
Floriculture/bulbs	4 (0.2)	7 (0.3)	130 (5.7)	361 (15.8)
Corn	27 (1.2)	75 (3.3)	662 (28.9)	1248 (54.5)
Potatoes	21 (0.9)	48 (2.1)	298 (13)	563 (24.6)

4. Discussion

We assessed environmental exposure to pesticides at the residential addresses for participants of a Dutch birth cohort study using spatial data on the presence of crops and survey data on agricultural pesticides use by farmers from existing sources. We used this information to estimate the crop surface area cultivated with selected, relevant crops and the amount of agricultural pesticides used within different distances of the participants' homes for the year 2012. Distances represent different exposure pathways including direct pesticide drift over short distances (50 and 100 m) and secondary transport processes over larger distances (500 and 1000 m) (Gunier et al., 2011; Hogenkamp et al., 2003; Simcox et al., 1995). We observed that a small proportion of the study participants lived in close proximity (<50 or <100 m) to agricultural fields with selected crops relevant for pesticide use in The Netherlands. The percentage of study homes within 500 or 1000 m from agricultural fields was much larger.

More than 10% of the study homes had cereals, vegetables, commercial crops, floriculture/bulbs, corn and/or potatoes within 500 and 1000 m distances. Crops mapped in proximity to homes using GIS have been used as a tool for estimating environmental exposure to agricultural pesticides before, e.g. (Brouwer et al., 2017; Nuckols et al., 2007; Rull et al., 2009). Studies from the United States (Gunier et al., 2011; Ward et al., 2006) have shown that the presence of vegetables, corn and strawberry agricultural fields within 500, 750 and even 1250 m distance of homes is associated with increased pesticide concentrations in homes. The findings of the US studies, however, likely do not directly apply to our study due to different application methods in The Netherlands and in the US, where aerial pesticide spraying is more common.

In our study, we considered the presence of agricultural fields within distances of up to 1000 m around children's homes as relevant for environmental exposure to agricultural pesticides. This assumption is supported by a previous study from The Netherlands, using a similar methodology as ours, that found that measured pesticide concentrations in air and rainfall were correlated with modelled pesticides at distances of up to 1 km (Brouwer et al., 2017). Our analysis showed that the surface areas cultivated with crops relevant for pesticide use in The Netherlands within 50 and 100 m distance from participants' homes were relative small. However, we found that relatively large areas within 500 and 1000 m distance from study homes were cultivated with corn, cereals, and potatoes. The surface area cultivated with corn around homes has been used as surrogate for environmental exposure to pesticides and associated with birth defects in a study from the United States (Ochoa-Acuña and Carbajo, 2009). We recognize, however, that the relevance of the surface area cultivated with specific crops for environmental exposure to pesticides apart from the size of the fields depends on factors such as the amount of agricultural pesticides applied and crop rotation.

Physical and chemical properties of agricultural pesticides are important predictors of pesticide concentrations in the environment as they influence how agricultural pesticides behave after application. Agricultural pesticides can be transferred from agricultural fields to homes by drift during application or, subsequently, through volatilization from soil, plants or wind erosion depending on physical chemical properties (Van Dijk and Guicherit, 1999).

Table 2
Distribution of the area (m^2) of crops with likely pesticide use within 50, 100, 500 and 1000 m of the PIAMA participants' home addresses at the time of the 14-year follow up (N = 2291).

Radius of circular buffer		Any of the selected crops	Orchard	Cereals	Vegetables	Commercial crops	Floriculture	Corn	Potatoes
50 m	P95	0	0	0	0	0	0	0	0
	Max	7439	853	6200	0	1359	2129	1765	3139
100 m	P90	0	0	0	0	0	0	0	0
	P95	1516	0	0	0	0	0	0	0
	Max	30,480	8215	20,414	2656	7419	8609	15,332	15,508
500 m	P50	0	0	0	0	0	0	0	0
	P75	28,324	0	0	0	0	0	5053	0
	P90	126,144	0	20,192	0	0	0	48,617	9639
	P95	214,430	0	65,966	0	25,965	1387	82,895	57,385
	Max	657,875	216,594	338,345	190,317	182,389	245,071	274,360	389,635
1000 m	P25	0	0	0	0	0	0	0	0
	P50	50,030	0	0	0	0	0	11,539	0
	P75	273,513	0	23,530	0	0	0	118,951	0
	P90	723,067	0	196,987	1909	70,715	5931	251,724	173,713
	P95	1,148,806	560	412,372	41,566	149,787	15,060	353,419	374,792
	Max	2,648,566	659,363	1,325,338	606,518	631,099	1,701,590	870,207	1,240,584

In this study, we estimated the amount of agricultural pesticides applied within distances of 50, 100, 500 and 1000 m of the children's homes and estimated that relatively large quantities of chlormequat, diquatdibromide, mancozeb, pencycuron, pendimethalin, prosulfocarb, terbuthylazine and sulphur were applied within these buffers. As their vapour pressure at 25° C ranges from 4.1×10^{-04} to 1.94, some of these pesticides are considered to be compounds with low volatility (University of Hertfordshire, 2016) but other pesticides like pendimethalin and terbuthylazine were still detected in air and precipitation in Europe (Van Dijk and Guicherit, 1999). Also, it has been shown that up to 90% of the amount of these pesticides applied on agricultural fields can be volatilized into the atmosphere (Bedos et al., 2002b; Unsworth et al., 1999). A study conducted in France has shown that even pesticides with low volatility were detected in particles in outdoor air (Bedos et al., 2002a). These studies support our assumption of agricultural pesticides being detectable within smaller (<100 m) and larger (500 and 1, 000 m) distances from agricultural fields.

Take-home pesticide exposure by farmers, in addition to proximity to treated fields, is another source of children's exposure to pesticides that is not accounted for in the present exposure assessment. However, the percentage of children living on a farm is low in the current study sample: 2% lived on a farm during the first year of life and at the age 5 years. Nevertheless, this needs to be taken into account in future epidemiological analyses.

We found a strong association between the total area of cropland and the estimated total amounts of pesticides applied on those crops (Table 3 and Supplementary Table 4). However, correlations between amounts of individual pesticides and between areas cultivated with individual groups of crops were often low to moderate ($r_s < 0.5$). This opens the possibility to investigate associations between crop group

Table 3
Associations between categorized surface area of crops cultivated and amount of agricultural pesticides with known irritant properties for the respiratory system used within 50, 100, 500 and 1000 m of the PIAMA participants' homes (N = 2291).

Radius of circular buffer	Agricultural pesticides	Area of crops (m^2)				Total	Weighted kappa
50 m	Amount agricultural pesticides associated with respiratory outcomes (g) (n = 16)	0	>0–437	≥437–1074	≥1074		0.81
	0	2221	3	3	3	2230	
	>0–26	0	13	7	1	21	
	≥26–106	0	4	10	6	20	
	≥106	0	4	3	13	20	
	Total	2221	24	23	23	2291	
100 m	Amount agricultural pesticides associated with respiratory outcomes (g) (n = 22)	0	>0–1696	≥1696–5230	≥5230		0.84
	0	2121	8	5	5	2139	
	>0–95	0	37	12	2	51	
	≥95–511	0	8	24	18	50	
	≥511	0	4	15	32	51	
	Total	2121	57	56	57	2291	
500 m	Amount agricultural pesticides associated with respiratory outcomes (g) (n = 25)	0	>0–22,247	≥22,247–93,484	≥93,484		0.88
	0	1365	28	11	0	1404	
	>0–1039	0	238	55	0	293	
	≥1039–6010	0	31	182	80	293	
	≥6010	0	9	58	234	301	
	Total	1365	306	306	314	2291	
1000 m	Amount agricultural pesticides associated with respiratory outcomes (g) (n = 25)	0	>0–92,598	≥ 92,598–317,994	≥ 317,994		0.87
	0	811	42	1	0	854	
	>0–4259	0	401	74	0	475	
	≥4259–23,217	0	39	324	111	474	
	≥23,217	0	7	89	392	488	
	Total	811	489	488	503	2291	

specific surface areas or estimated amounts of specific pesticides used and health outcomes in future applications of our exposure assessment methodology.

Our study has several limitations. We currently do not know how relevant the estimated crop areas and amounts of agricultural pesticides used are for long term exposure studies as this depends on crop rotation, changes in pesticide use over time as well as changing application practices.

Another limitation of this study is that we did not have actual measurements of pesticide concentrations in house dust or biological samples to compare with the estimated amount of pesticides applied within the buffers surrounding children's homes. We therefore have no direct information on the validity of our exposure estimates although the previously mentioned study from The Netherlands suggested reasonable agreement with measured concentrations of selected pesticides in air and in rainfall (Brouwer et al., 2017). Finally, there are no data on pesticides used on specific fields. Consequently, we are unable to estimate pesticide exposure other than assuming that the average amounts of pesticides applied to specific crops in The Netherlands (self-reported use data by farmers, collected in the agricultural census) apply to each agricultural field where the crop is cultivated.

5. Conclusions

We observed that a small proportion of the study participants lived in close proximity (<50 or <100 m) to agricultural fields with crops based on pesticide use. The percentage of study homes within 500 or 1000 m from agricultural fields was much larger. We also observed large amounts of individual pesticides associated with respiratory irritation were applied within 500 and 1000 m buffers. This means, in future work, we will use these data to investigate associations with respiratory disease endpoints.

Funding sources

The PIAMA study is supported by The Netherlands Organization for Health Research and Development; The Netherlands Organization for Scientific Research; The Netherlands Asthma Fund/Netherlands Lung Foundation; The Netherlands Ministry of Spatial Planning, Housing, and the Environment; and The Netherlands Ministry of Health, Welfare, and Sport. Joseph Bukalasa was supported by a fellowship from the IRAS foundation. The sponsors had no role in designing the study; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

Conflict of interest statement

None of the authors declares an actual or potential conflict of interest.

Acknowledgement

The authors would like to thanks Statistics Netherlands (CBS) for providing the information of the agricultural pesticides survey.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2017.03.269.

References

Bedos, C., Cellier, P., Calvet, R., Barriuso, E., 2002a. Occurrence of pesticides in the atmosphere in France. Agronomie 22, 35–49.
Bedos, C., Cellier, P., Calvet, R., Barriuso, E., Gabrielle, B., 2002b. Mass transfer of pesticides into the atmosphere by volatilization from soils and plants: overview. Agronomie 22, 21–33.
Booth, B.J., Ward, M.H., Turyk, M.E., Stayner, L.T., 2015. Agricultural crop density and risk of childhood cancer in the midwestern United States: an ecologic study. Environ. Health 14, 82.
Bouvier, G., Seta, N., Vigouroux-Villard, A., Blanchard, O., Momas, I., 2005. Insecticide urinary metabolites in nonoccupationally exposed populations. J. Toxicol. Environ. Health B 8, 485–512.
Brouwer, M., Kromhout, H., Vermeulen, R., Duyzer, J., Kramer, H., Hazeu, G., et al., 2017. Assessment of residential environmental exposure to pesticides from agricultural fields in the Netherlands. J. Expo. Sci. Environ. Epidemiol. (in press).
Chevrier, C., Serrano, T., Lecerf, R., Limon, G., Petit, C., Monfort, C., et al., 2014. Environmental determinants of the urinary concentrations of herbicides during pregnancy: the PELAGIE mother–child cohort (France). Environ. Int. 63, 11–18.
Deziel, N.C., Friesen, M.C., Hoppin, J.A., Hines, C.J., Thomas, K., Freeman, L., 2015. A review of nonoccupational pathways for pesticide exposure in women living in agricultural areas. Environ. Health Perspect. 123, 515–524.
Dutch Ministry of Interior and Kingdom Relations, 2013. Data Portal of the Dutch government. 2016.
FOCUS Working Group, 2008. Pesticides in Air: Considerations for Exposure Assessment. European Union, Brussels, p. 327 (SANCO/10553/2006 Rev, June 2).
Gunier, R.B., Ward, M.H., Airola, M., Bell, E.M., Colt, J., Nishioka, M., 2011. Determinants of agricultural pesticide concentrations in carpet dust. Environ. Health Perspect. 119.
Harnly, M.E., Bradman, A., Nishioka, M., McKone, T.E., Smith, D., McLaughlin, R., 2009. Pesticides in dust from homes in an agricultural area. Environ. Sci. Technol. 43.
Hogenkamp, A., Vaal, M., Heederik, D., 2003. Pesticide exposure in dwellings near bulb growing fields in The Netherlands: an explorative study. Ann. Agric. Environ. Med. 11, 149–153.
Lewis, R., Fortmann, R., Camann, D., 1994. Evaluation of methods for monitoring the potential exposure of small children to pesticides in the residential environment. Arch. Environ. Contam. Toxicol. 26, 37–46.
National Georegistry, 2012. BRP Crop Plots. 2015, The Netherlands.
Nuckols, J.R., Gunier, R.B., Riggs, P., Miller, R., Reynolds, P., Ward, M.H., 2007. Linkage of the California pesticide use reporting database with spatial land use data for exposure assessment. Environ. Health Perspect. 684–689.
Ochoa-Acuña, H., Carbajo, C., 2009. Risk of limb birth defects and mother's home proximity to cornfields. Sci. Total Environ. 407, 4447–4451.
Rappazzo, K.M., Warren, J.L., Meyer, R.E., Herring, A.H., Sanders, A.P., Brownstein, N.C., et al., 2016. Maternal residential exposure to agricultural pesticides and birth defects in a 2003 to 2005 North Carolina birth cohort. Birth Defects Res. A Clin. Mol. Teratol. 106, 240–249.
Rull, R.P., Gunier, R., Von Behren, J., Hertz, A., Crouse, V., Buffler, P.A., et al., 2009. Residential proximity to agricultural pesticide applications and childhood acute lymphoblastic leukemia. Environ. Res. 109, 891–899.
Salameh, P., Baldi, I., Brochard, P., Raherison, C., Saleh, B.A., Salamon, R., 2003. Respiratory symptoms in children and exposure to pesticides. Eur. Respir. J. 22, 507–512.
Schwartz, N.A., von Glascoe, C.A., Torres, V., Ramos, L., Soria-Delgado, C., 2015. "Where they (live, work and) spray": pesticide exposure, childhood asthma and environmental justice among Mexican-American farmworkers. Health Place 32, 83–92.
Simcox, N.J., Fenske, R.A., Wolz, S.A., Lee, I.-C., Kalman, D.A., 1995. Pesticides in household dust and soil: exposure pathways for children of agricultural families. Environ. Health Perspect. 103, 1126.
Statistics Netherlands (CBS), 2012. Pesticide Use in Agriculture. 2015.
University of Hertfordshire, 2016. Pesticide Properties DataBase. 2016.
Unsworth, J., Wauchope, R., Klein, A., Dorn, E., Zeeh, B., Yeh, S., et al., 1999. Significance of the long range transport of pesticides in the atmosphere. Pure Appl. Chem. 71, 1359–1383.
Van Dijk, H.F., Guicherit, R., 1999. Atmospheric dispersion of current-use pesticides: a review of the evidence from monitoring studies. Fate of Pesticides in the Atmosphere: Implications for Environmental Risk Assessment. Springer, pp. 21–70.
Van Dijk, H.F., Van Pul, W.A.J., De Voogt, P., 1999. Fate of Pesticides in the Atmosphere: Implications for Environmental Risk Assessment. Springer.
Ward, M.H., Lubin, J., Giglierano, J., Colt, J.S., Wolter, C., Bekiroglu, N., 2006. Proximity to crops and residential exposure to agricultural herbicides in Iowa. Environ. Health Perspect. 114.
Wijga, A.H., Kerkhof, M., Gehring, U., de Jongste, J.C., Postma, D.S., Aalberse, R.C., et al., 2014. Cohort profile: the Prevention and Incidence of Asthma and Mite Allergy (PIAMA) birth cohort. Int. J. Epidemiol. 43, 527–535.
Xu, X., Nembhard, W.N., Kan, H., Becker, A., Talbott, E.O., 2012. Residential pesticide use is associated with children's respiratory symptoms. J. Occup. Environ. Med. 54, 1281–1287.