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# Determinants of non-dietary exposure to agricultural pesticides in populations living close to fields: a systematic review

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## 1 **Abstract**

2 Background: There is growing evidence in the scientific literature that individuals living near  
3 fields are more exposed to agricultural pesticides than people living further away.

4 Objective: The main objective of this systematic review was to identify the non-dietary  
5 determinants of pesticide exposure related to the drift pathway in residents living in  
6 agricultural areas, including spatial indicators related to agricultural activities, hygiene  
7 practices, behaviors and sociodemographic parameters.

8 Methods: Three databases were consulted (PubMed, Web of sciences, Scopus). At least two  
9 experts selected the eligible studies.

10 Results: A total of 27 original studies (2002-2020) fulfilled the eligibility criteria of this review.  
11 These publications explored pesticide exposure of individuals through measurements in  
12 biological samples (n=13), environmental samples (n=11) or both (n=3). Spatial indicators,  
13 including residential proximity to fields, crop acreage around the residence and amounts of  
14 pesticides applied in the vicinity were identified as determinants of pesticide exposure in  
15 many studies (n=17), including publications considered to be of very good or good quality  
16 (n=12). Season of spraying tended to increase the levels of pesticides measured in five  
17 publications out of seven. Meteorological parameters and physical barriers showed an  
18 inconsistent and complex influence on the presence and levels of pesticides in urine samples  
19 and house dust. Frequent housekeeping reduced the presence of pesticides at home and  
20 consequently in biological matrices in three studies out of six. Finally, the effect of the  
21 occupants' sociodemographic characteristics, behaviors, and hygiene practices on the  
22 exposure measurement were less well documented and results were fairly inconsistent.

23 Discussion and conclusion: This study consolidates our knowledge of the determinants  
24 influencing pesticide exposure levels in people living in agricultural areas. Nevertheless, the  
25 available scientific data is still too limited to serve as a basis for developing risk management  
26 measures. More research is needed to improve knowledge of the determinants of exposure.

## 27 **Keywords**

28 Pesticides, Agriculture, Environmental exposure, Residents, Spray drift, Exposure  
29 determinants

## 30 **1. Introduction**

31 Individual exposure to pesticides may result from a combination of several potential sources:  
32 1/agricultural and non-agricultural work associated with direct and/or indirect pesticide  
33 exposure, 2/contact with people occupationally exposed to pesticides, 3/household pesticide  
34 use, 4/dietary ingestion of contaminated food and water, and 5/environmental exposures  
35 related to pesticide application in fields or manufacturing (U.S. EPA, 2020). The relative  
36 contribution of each of these sources can be difficult to discern and human can be exposed  
37 through dermal, oral, or respiratory routes leading to short-term and chronic health impacts  
38 (Kim et al., 2017).

39 For people living close to agricultural areas, the agricultural drift pathway could contribute  
40 substantially to total exposure. Several studies have indeed demonstrated higher levels of  
41 pesticides in both biological and environmental matrices among agricultural communities  
42 compared to people residing away from agricultural land (Dereumeaux et al., 2020). The  
43 agricultural drift pathway includes several transfer processes. Transfer of pesticides into the  
44 atmosphere can occur directly during pesticide application by spray drift from the fields which  
45 then forms deposits (primary drift). Aerial emissions can also arise for several days or weeks  
46 after application by volatilization of pesticides from soils and plants or by wind erosion  
47 (secondary drift) (Bedos et al., 2002; FOCUS, 2008). These phenomena can result in the  
48 exposure of residents to pesticides via dermal, inhalation and ingestion routes (EFSA, 2014).  
49 Associations between pesticide exposure and the onset of a variety of adverse health  
50 outcomes such as cancers, neurological diseases, and adverse effects on fertility or  
51 pregnancy in populations living close to agricultural crops have been reported in the scientific  
52 literature (Teyssere et al., 2020). Improving knowledge of the factors that may influence  
53 pesticide exposure near treated fields is essential in order to design intervention strategies  
54 that reduce potential impacts on the population's health. We found two systematic reviews,

55 by the same authors, on the determinants of non-dietary exposure to pesticides in  
56 agricultural areas. Deziel et al. (2015) published a review on non-occupational pathways of  
57 pesticide exposure in women living in agricultural areas in North America, not involved in  
58 farm work: ten out of 35 publications (1995–2013) reported significant or suggestive ( $p < 0.1$ )  
59 associations between agricultural drift pathway and pesticides in house dust or biomarker  
60 levels. The authors found moderate evidence of the efficiency of hygiene behaviors in  
61 reducing exposure. The second review on the relative contribution of non-occupational  
62 pathways to pesticide levels in house dust was based on seven studies covering the period  
63 1995-2015, and indicated that pesticide concentrations in house dust decreased sharply and  
64 non-linearly as the distance of the home from treated fields increased, the magnitude  
65 depending on the type of pesticides (Deziel et al., 2017). These reviews focused on specific  
66 populations (women or children, often members of farming families), sample types (house  
67 dust mainly) and location (North America). We propose a broader systematic review to  
68 describe the existing literature on non-dietary determinants of exposure related to the drift  
69 pathway in populations living near treated fields, including spatial indicators related to  
70 agricultural activities, hygiene practices, behaviors and sociodemographic parameters.

## 71 **2. Methods**

### 72 **2.1. General framework for the review**

73 We conducted a systematic review driven by the following question: “What are the  
74 determinants of non-dietary exposure to agricultural pesticides in people living near treated  
75 fields?”. We defined the determinants of exposure as the factors explored in the studies that  
76 could explain the levels of pesticide exposure as spatial indicators related to agricultural  
77 activities, hygiene parameters, behaviors, and sociodemographic data.

78 This work has been reported following the PRISMA guidelines (Moher et al., 2009).

### 79 **2.2. Literature Search**

80 The search for articles relied on three online bibliographic databases chosen for their  
81 complementarity in terms of the research areas covered: PubMed

82 (<https://pubmed.ncbi.nlm.nih.gov>), Web of sciences (  
83 <https://clarivate.com/webofsciencegroup/solutions/web-of-science>) and Scopus  
84 (<https://www.scopus.com>). We used the following algorithm: (pesticide\* OR fungicide\* OR  
85 herbicide\* OR insecticide\*) exposure\* AND ((proximity AND (field OR crop\* OR agricultur\*))  
86 OR (residen\*) OR ((agricultural OR rural) AND (communit\* OR area\*))). We added articles  
87 identified from websites or from the bibliographic references of the selected studies. The  
88 references were managed using Mendeley Reference Manager (Mendeley - Reference  
89 Management Software & Researcher Network).

### 90 **2.3. Study Eligibility Criteria**

91 To be included in our review, studies had to fulfill the following criteria:

92 1) original human studies published in English, French or Spanish.

93 2) studies referring to ground application of pesticides in agriculture. We excluded studies  
94 mentioning aircraft-mounted sprayers. The scale and speed of this kind of operation differ  
95 from ground spraying; the levels and profiles of exposure are *a priori* different for populations  
96 in the vicinity.

97 3) studies including a 'spatialized' definition of the term 'resident', e.g. studies providing  
98 numerical spatial indicators such as the residential distance from fields or the agricultural  
99 amounts of pesticides applied in the vicinity. We did not consider a maximum distance from  
100 the treated field. Indeed, there is no harmonized definition of the term "resident" in the  
101 scientific literature based on distance to fields. A qualitative definition such as "rural area"  
102 was not considered as sufficient to define a resident but this information could have been  
103 studied as a potential determinant of exposure. As our main objective was to study exposure  
104 determinants linked to the agricultural drift pathway, we chose to exclude studies including  
105 exclusively farmworkers and/or their families. Indeed, previous reviews have demonstrated  
106 that it is difficult to disentangle the contribution of the agricultural drift pathway from other  
107 sources in these populations because of the major contribution of the take-home exposure  
108 route (Deziel et al., 2015; Hyland and Laribi, 2017). However, studies including farmers'

109 families and other people living near crops but not involved in agricultural work were  
110 retained.

111 4) non-experimental studies characterizing residents' exposure to pesticides using  
112 biomonitoring or environmental monitoring and which quantitatively assess the effect of  
113 potential exposure determinants.

114 No limitations on the date of publication or the geographical location were applied.

115 The relevant studies were selected by three reviewers (RT, GM, FD). For each article, the  
116 eligibility criteria were checked by two reviewers independently. A consensus was found  
117 between all the reviewers about inclusion/exclusion of the article in the event of  
118 disagreement.

#### 119 **2.4. Data collection and analysis**

120 For each article, the following information was collected: study reference, location, time  
121 period, population, pesticides or metabolites searched for, matrices of exposure explored,  
122 determinants of exposure to the agricultural pesticides studied, methods of measuring these  
123 determinants, and key findings. The results were summarized in tables. We also collected  
124 information on the type of statistical analysis performed and the associations found by the  
125 authors, which we have presented in the appendices.

126 We presented results of multivariable tests rather than univariate statistical tests when both  
127 were available, focusing on the results on the determinants explaining the presence/absence  
128 of pesticides rather than the factors predicting the levels of pesticide exposure. When only  
129 univariate statistical tests were performed, this was specified in the presentation of the  
130 results.

131 We designed a specific reading grid to assess the adequacy of the selected publications to  
132 answer the research question presented above, based on the analysis of the potential bias of  
133 each study. Indeed, we did not find any validated grid to assess the quality of studies in the  
134 field of exposure science directly applicable to our subject. The grid detailing the score  
135 calculation method is available in a supplemental file (Appendix A). Briefly, five criteria were

136 used: 1) population adequacy, 2) reliability of exposure measurement, 3) reliability of spatial  
137 determinants measurement, 4) reliability of non-spatial determinants measurement, 5)  
138 consideration of other sources of exposure for the pesticides under study. A score from 0 to  
139 2 was calculated for each item when applicable, according to the criteria presented in the  
140 grid. The total score for an article was a mean of the score obtained for each relevant item  
141 expressed as a percentage of the maximal possible score. Publications were classified into  
142 four categories based on their adequacy score: A 'very good quality' (score above 75%), B  
143 'good quality' (between 50 and 74%), C 'medium quality' (between 25 and 49%), D 'low  
144 quality' (less than 25%).

### 145 **3. Results**

#### 146 ***3.1. Study selection***

147 The search for articles in the selected databases was conducted on January 10, 2020. We  
148 included 27 publications in our review: 26 were identified through the databases and one was  
149 found in the grey literature (Figure 1). This document was a thesis. The main reasons for  
150 exclusion were: no mention of pesticides used in agriculture, no human population included,  
151 and inclusion of populations not considered as residents (workers or general population).

#### 152 ***3.2. General characteristics of included studies***

153 The 27 articles included in our review were published between 2002 and 2020. They were  
154 from North America (n=14, 51.9%), Europe (n=8, 29.6%), Asia (n=3, 11.1%), South America  
155 (n=1, 3.7%), and Australia (n=1, 3.7%). The description of the type of crops near the  
156 residence was often missing (n=13, 48.1%). When the information was available, the crops  
157 identified, sometimes in association, were fruit trees (n=9, 33.3%), arable crops (n=6,  
158 22.2%), vineyards (n=4, 17.8%), vegetables (n=4, 14.8%), and flowers (n=3, 11.1%).

159 In 13 studies (48.1%), pesticide exposure was assessed only by biomonitoring, mainly  
160 measurements of pesticides in urine samples (n=12, 44.4%), maternal blood, umbilical cord  
161 blood and placental tissue (n=1) (Takser et al., 2004) and one study sampled prenatal dentin  
162 of shed teeth (n=1) (Gunier et al., 2013). The publications covered mainly insecticides and

163 their metabolites, such as organophosphates (OP) and their metabolites and notably Dialkyl  
164 phosphate (DAPs) (n=7), pyrethroids (PYR) and their metabolites (n=4) or imidacloprid and  
165 its metabolite (n=1). Two studies searched for herbicides and two for fungicides and their  
166 potential metabolites, such as ethylenethiourea (u-ETU). Finally, two searched for  
167 manganese (Mn) as an indirect measure of Mn-based fungicides such as maneb or  
168 mancozeb. The populations included in studies performing biomonitoring were children (n=7,  
169 53.8%), pregnant or post-partum women (n=4, 30.8%) or families (n=2, 15.4%). The main  
170 results yielded by the biomonitoring studies regarding exposure determinants potentially  
171 related to the agricultural drift pathway are presented in Table 1. More details on these  
172 results (type of statistical analysis performed, associations found) are presented in Appendix  
173 B.

174 Pesticides were measured only in environmental matrices in 11 studies (40.7%). Nine  
175 sampled house dust (n=9, 33.3%). Occasionally, pesticides were measured in air or in  
176 surface deposition samples using passive air samplers (n=1, 3.7%) and silicone wristbands  
177 (n=1, 3.7%). Pesticides investigated in the environment were mainly insecticides including  
178 OP (n=6) and/or PYR compounds (n=2), followed by herbicides (n=3) and other pesticides  
179 (n=4). In studies conducting environmental monitoring, populations living in the dwellings  
180 were rarely described. Results of environmental studies are presented in Table 2 and  
181 Appendix B.

182 Finally, three studies explored both biological and environmental matrices (11.1%): two  
183 combined measurements in house dust and urines and one collected wipe samples from  
184 hands, feet, diverse surfaces in the home, and blood samples. Two of these three studies  
185 investigated OP pesticides and one PYR pesticides. Results of these studies are presented  
186 in Table 3 and Appendix B.

187 The quality of the studies was variable: seven articles were classified in category A (25.9%),  
188 eight in category B (29.6%), nine in category C (33.3%) and finally three in category D

189 (11.1%). Details on the score calculated for each study are presented in a supplemental file  
190 (Appendix C).

191 In addition, 18 articles (66.7%) also investigated occupational and para-occupational  
192 determinants of exposure, 16 (59.3%) explored the contribution of factors related to the  
193 household use of pesticides, and 9 (33.3%) investigated dietary factors.

### 194 **3.3. Spatial determinants of exposure**

#### 195 *3.3.1. Place of residence (rural vs. urban)*

196 Studies of various quality established a positive association between living in a rural area  
197 and the detection rate or levels of pesticides in urine samples (Babina et al., 2012; Chevrier  
198 et al., 2014; Dereumeaux et al., 2018), silicone wristbands (Harley et al., 2019) and blood  
199 (Takser et al., 2004). Two medium or low quality studies found, conversely, a positive  
200 association between living in an urban area and levels of OP, PYR and/or herbicide  
201 metabolites in urine samples (Fernandez et al., 2020; Munoz-Quezada et al., 2012).

#### 202 *3.3.2. Residential proximity to fields*

203 Residential proximity to fields was the most common spatial determinant explored in the  
204 publications (n=16, 59.3%). A significant association between residential distance from the  
205 fields and pesticide measurements in different matrices was found in 12 of 16 studies (75%)  
206 of varying quality, seven being classified in category A or B and five in category C or D.

207 Seven studies showed a positive association between residential distance from fields within  
208 100 meters and elevated detection rates or concentrations of pesticides in urine samples and  
209 house dust. Three of these studies found an association for OP insecticides or its  
210 metabolites (DAPs) (Bradman et al., 2011; Butler-Dawson et al., 2018; Hung et al., 2018),  
211 two for the herbicide Dimethyl tetrachloroterephthalate (DCPA) (Harley et al., 2019; Harnly et  
212 al., 2009) , one for a metabolite of fungicides (ETU) (Sammartano et al., 2019), and one for  
213 several herbicides (Ward et al., 2006). Three studies did not report any association with  
214 pesticide exposure indicators in urine samples (Babina et al., 2012; Koch et al., 2002) or

215 house dust (Hogenkamp et al., 2004) and living within 100 meters of fields. The pesticides  
216 explored were diverse, including insecticides, herbicides, and fungicides.

217 Six studies explored associations for greater distances. Of these, five showed a positive  
218 association between residential distance from fields less than 500 meters and elevated  
219 pesticide concentrations in urine samples or air for OP pesticides and its metabolites (n=4)  
220 (Coronado et al., 2011; Fernandez et al., 2020; Gibbs et al., 2017; Munoz-Quezada et al.,  
221 2012) and for atrazine and triazine metabolites (n=1) (Chevrier et al., 2014). One study found  
222 no association between distances less than 500 meters and levels of OP metabolites in urine  
223 samples (Royster et al., 2002).

#### 224 3.3.3. Crop acreage in one or several buffers around the home

225 Five publications studied the influence of crop acreage in one or more buffers around the  
226 home. In GIS, a buffer is a zone specified around a point or a line or a polygon area. In all  
227 the studies selected, this zone was a circular polygon with a center determined by the  
228 residential location. Three out of five studies (60%), considered to be of very good or good  
229 quality, found a positive association between areas of arable crops, vineyards and/or  
230 orchards within 500 to 1000 meters from the home and higher levels of pesticides in house  
231 dust (Béranger et al., 2014; Glorennec et al., 2017; Ward et al., 2006). Among these studies,  
232 one also found an association between the distance to the closest crop field and herbicide  
233 exposure; however, distance alone accounted for less of the variance than crop acreage  
234 (Ward et al., 2006). One very good quality study found no association between surface area  
235 of orchards and residential concentrations of pesticides (Plascak et al., 2019). One medium  
236 quality study showed no association between the number of fields in the vicinity and urinary  
237 DAPs levels (Royster et al., 2002).

#### 238 3.3.4. Amounts of pesticides applied around the dwelling

239 Four analyses conducted in California from the Pesticide Use Report (PUR) dataset explored  
240 the effect of the amounts of agricultural pesticides applied near the home on the presence of  
241 pesticides in several matrices. In California, all agricultural and non-agricultural pesticide

242 uses are reported to the California Department of Pesticide Regulation. Information about  
243 crops, active substances, date and amount of pesticides applied, location of application, are  
244 compiled into the PUR data set with a resolution of 1.6 km (one mile) square sections  
245 (California Department of Pesticide Regulation). Three studies found significant  
246 associations between pesticide amounts applied around the home ( $\leq 3,000$  meters) and the  
247 presence in house dust of chlorpyrifos, iprodione, DCPA (Gunier et al., 2011; Harnly et al.,  
248 2009), phosmet, simazine (Gunier et al., 2011) and manganese (Mn) (Gunier et al., 2014).  
249 One of these studies also searched for the influence of the distance to the nearest field and  
250 found an influence of this parameter for DCPA (Harnly et al., 2009). Higher Mn levels in  
251 prenatal dentin of shed teeth collected from a population of 7-year-old children were also  
252 associated with the use of Mn-based fungicides within 3000 meters of the maternal  
253 residence during pregnancy in a medium quality study (Gunier et al., 2013).

#### 254 3.3.5. Other spatial indicators

255 Two publications found positive associations between proximity of school or child care to  
256 fields and the insecticide levels in children's urines and/or house dust (Glorennec et al.,  
257 2017; Tao et al., 2019) while two others did not find any association with urinary  
258 concentrations of several fungicides or insecticide metabolites (Bradman et al., 2011;  
259 Sammartano et al., 2019).

260 The observation by subjects of pesticide spraying from home showed no influence on the  
261 measure of pesticides in silicone wristbands (Harley et al., 2019). These results were  
262 inconsistent with those in another lower quality publication reporting a positive association for  
263 pesticide spraying less than 1 km away (Takser et al., 2004).

### 264 **3.4. Meteorological and topographical determinants of exposure**

#### 265 3.4.1. Season

266 The effect of season was investigated in seven studies. Four showed a significant increase in  
267 the urinary levels of OP metabolites (Bradman et al., 2011; Koch et al., 2002; Munoz-  
268 Quezada et al., 2012) and chlormequat (Galea et al., 2015) during spraying season

269 compared with the agricultural low-season, and two studies found higher urinary  
270 concentrations of atrazine and chlorpyrifos during winter (Chevrier et al., 2014; Galea et al.,  
271 2015). Variations of carbaryl concentrations in house dust were found in one study: levels  
272 were higher in fall than summer, spring, and winter (Gunier et al., 2011). One Asian study  
273 found no difference in pesticide concentrations in indoor and outdoor dust according to the  
274 season considered (warm/cold) (Hung et al., 2018).

#### 275 3.4.2. Meteorological and topographical determinants of exposure

276 All studies that included meteorological and topographical parameters were considered to be  
277 of very good or good quality.

278 The influence of daily rainfall prior to sampling yielded contradictory results. In two studies,  
279 an increase in precipitation on sampling days or in the month before sampling was  
280 associated with lower levels in urine samples and house dust for some OP pesticides  
281 (Bradman et al., 2011; Harnly et al., 2009), and with higher levels for other OP pesticides  
282 (Bradman et al., 2011). One publication found no association between precipitations during  
283 the last 4 and 8 weeks before sampling and Mn levels in house dust (Gunier et al., 2014).

284 The effect of temperature was studied in only one publication: increased temperatures on  
285 days prior to sampling were only associated with higher DCPA levels (Harnly et al., 2009).

286 The influence of wind direction on pesticide exposure was taken into account through the  
287 calculation of spatial indicators. Chevrier et al. (2014) developed a wind-weighted score for  
288 residential proximity to corn, while Béranger et al. (2014) investigated the influence of the  
289 crop acreage around the home for different buffer sizes, wind-weighted. Both studies found a  
290 positive association between these indicators and pesticide levels in biological and  
291 environmental matrices. Béranger et al. (2014) et al. found that the use of a wind-weighted  
292 indicator provided additional information compared with acreage alone and significantly  
293 improved the models used, whereas Chevrier et al. (2014) concluded that adding the  
294 prevailing wind into the models did not improve the prediction of urinary herbicide  
295 concentrations much. Finally, one study showed that the presence of vegetative barriers

296 between fields and homes, determined using GIS, reduced the presence and concentration  
297 of pesticides in house dust (Béranger et al., 2014).

### 298 **3.5. Sociodemographic determinants of exposure**

#### 299 *3.5.1. Age, gender and weight*

300 In children, a study observed that associations between determinants of pesticide exposure  
301 and urinary levels of insecticide metabolites differed by age when this parameter was  
302 considered as an interaction term in the models (Bradman et al., 2011). Two studies describe  
303 an inverse relationship among older children going to kindergarten or school (Munoz-  
304 Quezada et al., 2012; Tao et al., 2019). Three studies found no influence of age on exposure  
305 (Galea et al., 2015; Koch et al., 2002; Sammartano et al., 2019). Results for the effect of  
306 gender were also inconsistent: DAP levels in children's urines were higher in boys in one  
307 publication (Koch et al., 2002) and in girls in another (Bradman et al., 2011), while three  
308 studies observed no association (Munoz-Quezada et al., 2012; Sammartano et al., 2019;  
309 Tao et al., 2019).

310 In adults, one study found higher pesticide exposure in younger adults (Dereumeaux et al.,  
311 2018), whereas five found no association (Chevrier et al., 2014; Fernandez et al., 2020;  
312 Galea et al., 2015; Sammartano et al., 2019; Takser et al., 2004). The effect of gender was  
313 investigated in a single study which found that ETU concentration in urine samples was not  
314 associated with gender (Sammartano et al., 2019). A higher body mass index or weight was  
315 associated with lower pesticide levels (PYR, OP and herbicides) in one study (Fernandez et  
316 al., 2020) but was not found to be a determinant of pesticide exposure in two publications  
317 with a better quality score (Dereumeaux et al., 2018; Sammartano et al., 2019).

#### 318 *3.5.2. Other sociodemographic parameters*

319 No association was found between pesticide indicators of exposure and the educational level  
320 or the household income of subjects (Chevrier et al., 2014; Fernandez et al., 2020; Munoz-  
321 Quezada et al., 2012; Takser et al., 2004). Results were contradictory regarding the house  
322 density metrics (Béranger et al., 2014; Gunier et al., 2014; Harnly et al., 2009).

323 **3.6. Hygiene factors**

324 3.6.1. Housekeeping

325 Three studies with a high level of confidence found that the more frequently the house was  
326 cleaned, the lower the presence or concentrations of several pesticides in urine samples  
327 (Glorennec et al., 2017), house dust (Harnly et al., 2009), and silicone wristbands (Harley et  
328 al., 2019). These associations were not reported for all the pesticides studied, and two  
329 publications considered to be of very good or good quality observed no association between  
330 the frequency or the quality of house cleaning and pesticide contamination (Bradman et al.,  
331 2011; Butler-Dawson et al., 2018).

332 Increased time or frequency of window opening was associated with higher concentrations of  
333 certain pesticides only, i.e. p-nitrophenol in urine samples (Fernandez et al., 2020) and  
334 esfenvalerate in silicone wristbands (Harley et al., 2019). Two studies found no association  
335 at all (Butler-Dawson et al., 2018; Siritwat et al., 2019). Similarly, results regarding the  
336 influence of a ventilation system on OP pesticide exposure were inconsistent (Butler-Dawson  
337 et al., 2018; Harnly et al., 2009).

338 3.6.2. Other hygiene factors

339 Personal hygiene practices were studied in a single medium quality publication where  
340 frequent hand washing was associated with lower concentrations of chlorpyrifos residue on  
341 feet (Siritwat et al., 2019).

342 Three high quality studies found no influence of the presence of pets in the dwelling on  
343 urinary concentrations of DAPs (Bradman et al., 2011) or on the pesticides' presence or  
344 concentrations in indoor dust (Béranger et al, 2014) or in silicone wristbands (Harley et al.,  
345 2019).

346 Finally, the presence of carpeting in homes was associated only with the presence of DCPA  
347 in silicone wristbands (Harley et al., 2019); this parameter showed no influence on the  
348 urinary concentrations of DAPs (Bradman et al., 2011). The presence of doormats was  
349 associated with a lower presence of permethrin and piperonyl butoxide, a synergist

350 compound of pesticide products, in silicone wristbands (Harley et al., 2019) and with lower  
351 Mn in house dust (Gunier et al., 2014).

### 352 **3.7. Activities of the occupants**

353 Activities and behaviors of persons residing near agricultural fields were not extensively  
354 investigated. In one study, pesticide exposure was not associated with child behavior  
355 indicators (Bradman et al., 2011). Duration of play or sitting on the floor was associated with  
356 lower concentrations of chlorpyrifos on hands and feet in one study (Siriwat et al., 2019).  
357 Time spent inside and outside a building located near agricultural activities was not  
358 associated with pesticide levels in urine samples (Galea et al., 2015; Sammartano et al.,  
359 2019), except for one study of a child population (Bradman et al., 2011). Four studies found  
360 no influence of smoking on pesticide levels in urine samples (Chevrier et al., 2014;  
361 Fernandez et al., 2020; Galea et al., 2015; Takser et al., 2004), while one observed an  
362 association between the concentrations of pyrethroids in pregnant women's urines and their  
363 smoking habits (Dereumeaux et al., 2018). One publication found lower Mn levels in the  
364 deciduous teeth of children whose mothers smoked during pregnancy (Gunier et al., 2013).  
365 Smoking habits could lead to pesticide exposure, not only through the consumption of  
366 pesticide-treated tobacco leaves (Cai et al., 2002), but also because smoking is likely to  
367 increase hand-to-mouth carrying (Dereumeaux et al., 2018). None of the studies  
368 incorporating smoking habits was considered to be of good quality.

## 369 **4. Discussion**

370 The main objective of this systematic review was to identify the non-dietary determinants of  
371 exposure to agricultural pesticides in populations living near treated fields. Twenty-seven  
372 relevant studies were analyzed and provided consistent evidence about the role of the drift  
373 pathway in the overall pesticide exposure of people residing in agricultural areas, which is  
374 expected to be linked with atmospheric dispersion at the local range. Spatial indicators,  
375 reflecting agricultural activities, were the determinants studied most frequently and were  
376 found to be associated to pesticide levels or presence in urine samples or house dust in a

377 majority of studies, including high quality publications. Indicators of exposure were more  
378 frequently associated with the amounts of pesticides applied in the vicinity than other metrics  
379 such as crop acreage around the home or residential proximity to fields. Studies that  
380 explored several indicators confirmed that the amount of pesticide used locally better  
381 explained the level of exposure observed (Harnly et al., 2009; Ward et al., 2006). The studies  
382 reviewed here also found frequently increased urinary levels of pesticides during the  
383 treatment season compared with the non-spraying period, which is an additional argument in  
384 favor of the contribution of the agricultural drift pathway in exposure. These findings are in  
385 line with those from previous reviews conducted in other populations (farmworkers and their  
386 families, or other agricultural communities) which also identified many studies that concluded  
387 that people living near agricultural lands were more exposed to pesticides than people living  
388 elsewhere (Dereumeaux et al., 2020; Deziel et al., 2017; Deziel et al., 2015).

389 However, although these results may support the importance of the agricultural drift pathway  
390 overall, they remain inconsistent from one study to another, even for the same family of  
391 pesticides. The values of the spatial indicators associated with a significant effect on  
392 pesticide exposure varied greatly between publications. They ranged between 30 and 750  
393 meters for the residential distance from the fields. The indicators based on crop surfaces and  
394 amounts of pesticides applied, associated with exposure, had buffer radii ranging between  
395 500 and 3,000 meters. The disparities observed could be due to the large variations in study  
396 protocols. Sampling strategies were indeed very diverse regarding the matrix considered, the  
397 choice of exposure marker, the population followed, the temporality of measurements, and  
398 the analysis techniques. Moreover, in the scientific literature, several parameters have been  
399 identified as influencing the emission and dispersion of agricultural pesticides in ambient air,  
400 including the physico-chemical characteristics of compounds, the type of vegetation treated,  
401 the spraying equipment used (FOCUS, 2008). The values of these parameters were highly  
402 variable in the reviewed studies and could partially explain the differences observed in the  
403 results. Meteorological conditions during and after spraying also play a role in the emission

404 and transport of pesticides (FOCUS, 2008). High temperatures, or elevated wind velocity  
405 generally enhance the volatilization rate from plant and soils and consequently increase  
406 pesticide losses into the atmosphere (Bedos et al., 2002; FOCUS, 2008). Some of the  
407 studies we reviewed showed an influence of several of these variables on pesticide levels in  
408 urine samples or house dust but the results could sometimes be contradictory depending on  
409 the substance considered (Bradman et al., 2011; Harnly et al., 2009). Controlling some of the  
410 parameters linked to pesticides and their conditions of application could be a relevant way to  
411 reduce exposure among people living near treated fields and prevent adverse health effects.  
412 Sammartano et al. (2019) observed a significant reduction of u-ETU in adults and children  
413 after local stakeholders banned the use of mancozeb on vineyards. Other mitigation  
414 measures could also reduce residents' pesticide exposure, such as applying pesticides  
415 under favorable weather conditions, using drift reduction techniques or installing windbreaks  
416 at the edges of fields. The delimitation of no-spray buffer zones could also be proposed  
417 (FOCUS, 2007). As argued by Gunier et al. (2017), determining a safe distance or buffer  
418 should be based on the published literature about health effects related to pesticide  
419 exposure. However, the authors estimated that the scientific data was still limited to identify  
420 the correct distance that would protect public's health and that more research is needed in  
421 this field.

422 Exposure to pesticides also seems to depend on some sociodemographic parameters. In  
423 children, half of the studies investigating an effect of age showed that this was a possible  
424 determinant of exposure. In toddlers, some authors observed elevated levels of pesticides at  
425 12 and 24 months compared to 6-month-old children and they related these to changes in  
426 behaviors and diet (Bradman et al., 2011). After three years old, publications found an  
427 inverse relation between age and insecticide levels in urine samples. The authors argued  
428 that the higher concentrations found in younger children could be due to their smaller body  
429 size or their immature metabolism which might lead to longer pesticide half-lives in their  
430 body, but could also be related to specific behaviors (e.g., mouthing activity, hygiene habits,

431 time spent on the floor) (Munoz-Quezada et al., 2012; Tao et al., 2019). Some studies  
432 confirmed a possible effect of children's behaviors on their exposure to OP pesticides. Sitting  
433 on the floor, playing periods and time spent in child care have been associated with urinary  
434 levels of DAPs (Bradman et al., 2011; Siriwat et al., 2019). The effect of gender on the level  
435 of pesticide exposure remains inconsistent since two studies described as being of good or  
436 medium quality found opposite results, whereas the rest of the publications did not find any  
437 association. One article speculates that some differences in behavioral and/or activity  
438 patterns between boys and girls could cause exposure disparities. Boys may be more  
439 exposed because of a higher frequency of hand-to-mouth activity or strenuous physical  
440 activities (Koch et al., 2002). Finally, the effect of parental socioeconomic status has not  
441 been extensively studied. Parental education was investigated in a single publication and  
442 was not related to children's pesticide exposure. No conclusion can be drawn from this single  
443 study. The relationships between socioeconomic status and chemical levels of exposure in  
444 biological matrices can be very complex and give heterogeneous results according to the  
445 pollutant considered; higher exposures are not always found in poor and minority  
446 communities (Morrens et al., 2012; Tyrrell et al., 2013). In the case of pesticide exposure  
447 driven by the agricultural drift pathway, it would be difficult to hypothesize the effect of  
448 socioeconomic status on exposure and this question needs to be explored in future studies.

449 In adults, the results extracted from the selected studies do not favor an effect of age and  
450 gender on pesticide exposure, but information is still limited and comes from a study  
451 considered to be of lower quality. However, some biological factors could cause physical and  
452 metabolic disparities between men and women. Some behavioral differences could also lead  
453 to differentiate results according to gender. Women spend in general more time in a  
454 residential setting than men (Schweizer et al., 2007) and could be more exposed to  
455 pesticides by the agricultural drift pathway. Effects of behaviors and activities have not been  
456 investigated in the reviewed studies, except for smoking habits, which showed poor evidence  
457 for predicting the levels of pesticides in urine samples. Nor is it possible to distinguish the

458 contribution of hand-to-mouth contact that could be linked to contamination of homes located  
459 near agricultural fields by the consumption of pesticide-treated tobacco leaves.

460 The effects of age, gender, socioeconomic status and behaviors have been only rarely  
461 explored in adults and children and the trends observed need to be confirmed in further  
462 studies. Indeed, they are not usually investigated as determinants for exposure but are  
463 frequently used as *a priori* variables of adjustments in statistical modelling. By improving  
464 knowledge of these determinants, it could be possible to design targeted effective  
465 interventions in order to reduce exposure.

466 Residential exposure to pesticides could be modified by hygiene factors. Three of the studies  
467 we reviewed showed a positive impact of an elevated frequency or quality of house cleaning  
468 in the reduction of pesticides for several matrices (house dust, silicone wristbands and  
469 urines). These findings are consistent with those obtained in the environment of farmworkers  
470 and their families (Deziel et al., 2015; Quandt et al., 2006). Improving cleaning practices  
471 could be an effective leverage for reducing pesticide exposure. However, previous  
472 interventions promoting hygiene practices in farmworkers' homes gave mixed results (Griffith  
473 et al., 2019; Salvatore et al., 2015; Thompson et al., 2008). Two publications showing a  
474 positive effect of interventions on reducing pesticide exposure provided limited information  
475 about which behaviors or combination of behaviors and what level of compliance would most  
476 effectively prevent residential pesticide contamination (Griffith et al., 2019; Salvatore et al.,  
477 2015). Other hygiene factors were less explored: personal hygiene in children, and presence  
478 of a doormat were associated with lower indicators of exposure, whereas open windows  
479 seem related to higher exposure values. The presence of pets in the house and carpets on  
480 the floor were not associated with the pesticides measured in the environment. Hygiene  
481 factors should be investigated further in order to identify potential leverage to reduce  
482 residents' exposure to agricultural pesticides.

483 To our knowledge, this study is the first qualitative systematic review exploring the state of  
484 knowledge about non-dietary determinants of exposure conducted in a non-specific

485 population of residents. It can be compared with previous work carried out in other  
486 populations (children, women living in agricultural areas). This work has been reported using  
487 the PRISMA Guidelines. In addition, we created a subject-specific evaluation grid to interpret  
488 the biases of the studies from the perspective of our research question. However, there are  
489 limitations to this review. Few of the publications we selected were specifically designed to  
490 answer our research question. The populations selected in the reviewed publications could  
491 be very heterogeneous and frequently included farmworkers or their families. The  
492 contribution of the agricultural drift pathway may therefore be difficult to distinguish from  
493 other routes, such as the take-home or the residential exposure pathways. Indeed, some  
494 previous studies have shown that these routes could contribute substantially to overall  
495 exposure (Deziel et al., 2015; Hyland and Laribi, 2017; Quandt et al., 2006). Although the  
496 selected studies performed adjustments to the statistical modeling, some potential  
497 confounding factors could remain. Finally, the review we conducted was perhaps not totally  
498 exhaustive. Using a definition of “residents” based on spatial indicators, we may have  
499 wrongly considered some people living near treated fields as “general population”. Studies  
500 conducted by scientific institutions as part of environmental health policy are not usually  
501 published in the databases we consulted, and could probably not be identified despite  
502 consulting the grey literature. We might also have missed studies published in other  
503 languages than English, French or Spanish.

504 The results provided by this review are still too limited to comprehensively identify the  
505 determinants contributing substantially to the pesticide exposure linked to the drift pathway  
506 and they should be interpreted with caution. Future studies are needed to confirm the trends  
507 observed and acquire data on the poorly or insufficiently studied determinants. These studies  
508 should be specially designed to assess drift exposure. In their review published in 2020,  
509 Dereumeaux et al. (2020) developed a list of study characteristics to accurately measure  
510 spray-drift exposure in residents, and this could be used as a framework reference. It is  
511 indeed essential to improve knowledge of the determinants of exposure in order to design

512 appropriate interventions and thus reduce exposure and prevent health effects related to  
513 agricultural pesticides in populations at risk.

## 514 **5. Conclusion**

515 A majority of the studies we selected in our systematic review provided robust evidence for  
516 the contribution of the agricultural drift pathway in overall pesticide exposure in people living  
517 near fields. Several spatial indicators reflecting pesticide use around residences have been  
518 associated with elevated concentrations of agricultural pesticides in both biological and  
519 environmental matrices in residents. Other potential determinants of exposure such as  
520 sociodemographic characteristics, behaviors and hygiene practices have been less  
521 extensively studied. It is hoped that our knowledge of determinants of pesticide exposure  
522 could be improved from future studies specifically designed to explore this research question.  
523 Improving knowledge of the determinant of pesticide exposure due to the agricultural drift  
524 pathway is essential in order to design efficient and proportionate interventions and thus  
525 prevent the onset of adverse health effects in populations living near treated fields.

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531 **References**

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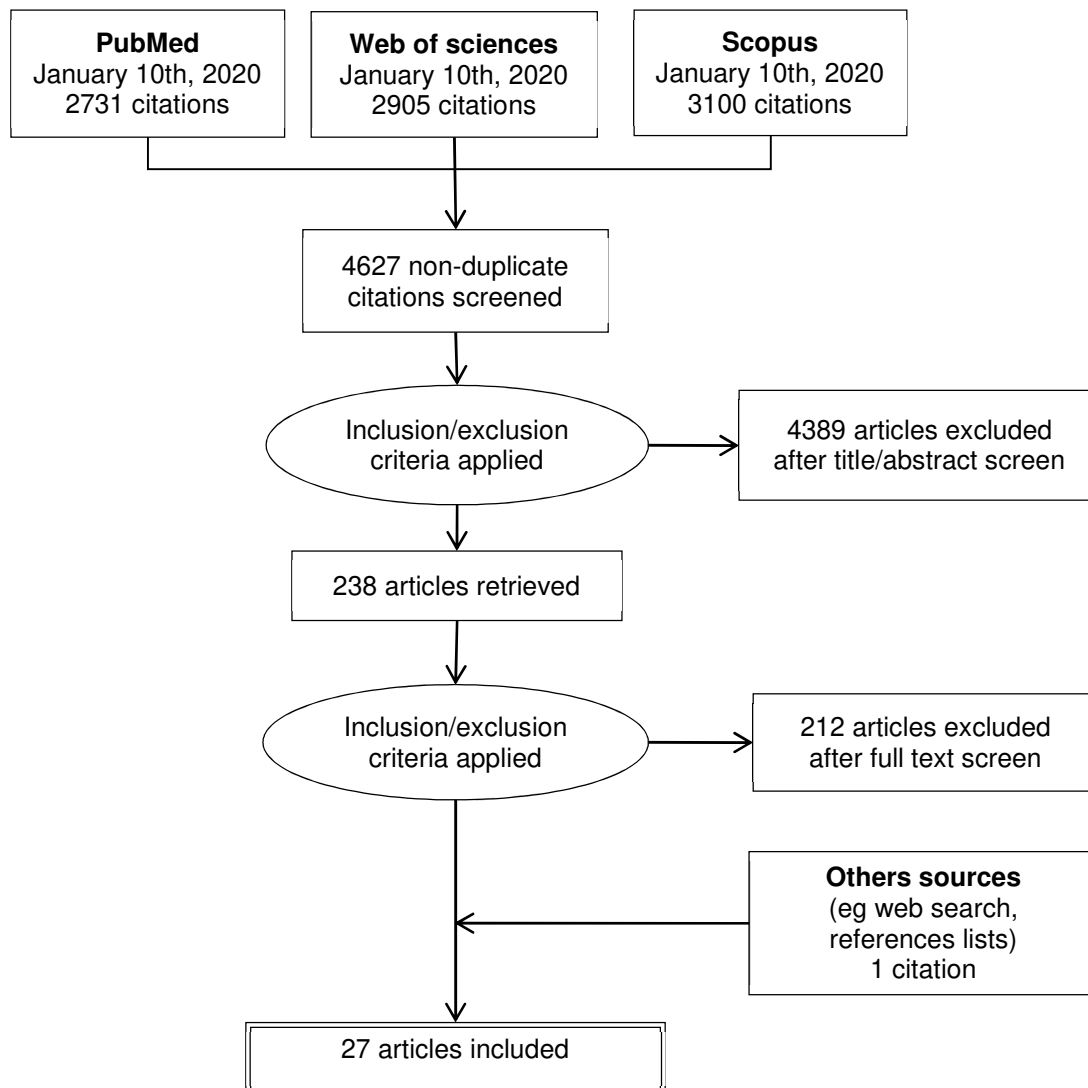
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**Figure 1 - Flow Diagram of study selection**

**Table 1 – Evidence for determinants of non-dietary exposure to agricultural pesticides linked to spray drift in people living close to fields in biomonitoring studies (n=13)**

Study reference	Location, Time period, Population	Exposure measurement	Determinants of exposure to agricultural pesticides studied	Measurement of exposure determinants	Determinants of exposure to pesticides (results from multivariate models)	Study score
(Babina et al., 2012)	Australia, 2003–2004, children aged <6 years (N=115 urban, 111 peri-urban, 114 rural)	Urines (1 sample): 8 OP and 4 PYR metabolites	Residential proximity to fields (<50 m or < 200m), area of residence (rural, urban), smoking	Self-administered questionnaire	– <i>3-Methyl-p-nitrophenol</i> , and <i>DMTP</i> detection Living in a periurban or rural area (+)	C
(Bradman et al., 2011)	USA, California, 2000-2003, children <2 years old, CHAMACOS cohort (N=416)	Urines (1 sample at 6, 12, 24 months of age): 6 OP metabolites (DAPs)	Age, gender, time in child care, child behavior, season, daily rainfall in the past week, residential or child care proximity to fields ≤60m, house cleaning frequency, presence of carpets, pets at home	Face-to-face interview	– <i>DEAPs</i> and <i>DMAPs</i> levels Average daily rainfall (- for <i>DMAPs</i> , -/+ for <i>DEAPs</i> ), living ≤60m from fields (+), summer/spring (+)	A
(Chevrier et al., 2014)	France, 2002-2006, pregnant women, PELAGIE cohort (N=579)	Urines (1 sample): 4 herbicides (acetochlor, alachlor, metolachlor, atrazine) and metabolites	Rural place of residence (<15% artificial surfaces in a 500-m radius), score of residential proximity to corn crops (wind-weighted or not), season, age, educational level, smoking	Self-administered questionnaire, GIS	– <i>Alachlor</i> presence Living in rural areas (+) – <i>Atrazine</i> and <i>triazine</i> metabolites presence Residential proximity to crops wind-weighted (+), winter (+)	B
(Dereumeaux et al., 2018)	France, 2011, pregnant women, Elfe cohort (N=1077)	Urines (1 sample): 5 PYR metabolites	Presence of crops <2000m from home, age, household income, BMI, smoking	Self-administered questionnaire, interview, GIS	– <i>Sum of pyrethroids</i> levels Smoking (+), living near orchards or vineyards (+), age (-) – <i>3-PBA</i> levels Living near orchards or vineyards (+)	B

Study reference	Location, Time period, Population	Exposure measurement	Determinants of exposure to agricultural pesticides studied	Measurement of exposure determinants	Determinants of exposure to pesticides (results from multivariate models)	Study score
(Fernandez et al., 2020)	Spain, 2015, post-partum women (n = 116)	Urines (1 sample): 20 metabolites of OP, PYR and herbicides	Age, BMI, country of birth, education level, occupational status, residential proximity to farms <200m, area of residence (rural, urban), daily time with windows open, smoking	Self-administered questionnaire	– <i>PNP concentrations (metabolite of parathion)</i> Living in rural area (-), windows opening (+) – <i>TCP concentrations (metabolite of chlorpyrifos-ethyl)</i> BMI (-), living < 200m from farming areas (+)	D
(Galea et al., 2015)	UK, 2011-2012, adults (N=118) and children (N=22) residing <100 m from fields	Urines (N=1518 samples): chlormequat and metabolites of captan (THPI), chlorpyrifos (TCP) or cypermethrin (DCVA)	Season (1-2 days after a spray event, during spraying season, during non-spraying season), gender, age, time spent indoors and outdoors	Self-administered questionnaire	– <i>Chlormequat levels</i> Sampling after spray event (+) – <i>Chlorpyrifos levels</i> Sampling after spray event (-)	A
(Gunier et al., 2013)	USA, California, 1999-2000, 7-year-old children, CHAMACOS cohort (N=207)	Prenatal dentin of shed teeth (N=324): Mn	Agricultural use of Mn fungicides near the maternal residence during pregnancy (<1, 3, and 5 km), smoking during pregnancy	Face-to-face interview, GIS	– <i>Mn levels</i> Agricultural use of pesticide within 3km around home (+), Smoking during pregnancy (-)	C
(Koch et al., 2002)	USA, Washington State, 1997-1998, 2–5-year-old children (N=44)	Urines (16 to 26 samples): five OP metabolites (DAPs)	Residential proximity to fields (<60m vs. >60m), season, age, gender	Face-to-face interview, GIS	– <i>Dimethyl and diethyl DAPs levels</i> Sampling during spray months (+), Male gender (+)	B
(Munoz-Quezada et al., 2012)	Chile, 2010-2011, 6-12-year-old children (N=190)	Urine samples (1 in fall and 1 in summer): 6 OP metabolites (DAPs)	Season, age, gender, parental education, residential proximity to farm (≤500m, > 500m), residential location (urban, rural)	Questionnaire	– <i>Sum of DEAPs levels</i> Age < 9 years (+), Living in urban area (+) – <i>DMAPs detection</i> Summer (+), Proximity to a farm ≤500m (+)	C

Study reference	Location, Time period, Population	Exposure measurement	Determinants of exposure to agricultural pesticides studied	Measurement of exposure determinants	Determinants of exposure to pesticides (results from multivariate models)	Study score
(Royster et al., 2002)	USA, California, 2000, Children aged 12–18 months (N=20)	Urines (1 sample): OP metabolites (DAPs)	Residential proximity to fields (<400m; 400-800m; 800-1600m; <1600m), living near multiple fields	Face-to-face interview, GIS	No association *	C
(Sammartano et al., 2019)	Italy, 2011-2014, 3–5-year-old children (N=126) and adults (N=260)	Urine (1 sample): u-ETU, metabolite of dithiocarbamates	Residential or school proximity to vineyards ( $\leq$ 30m, 31–200m, > 200m), size of the closest vineyards, gender, age, weight, time spent indoors	Self-administered questionnaire	– <i>u-ETU levels in children</i> Living $\leq$ 30m from vineyards (+)	C
(Takser et al., 2004)	Canada, pregnant women (N=101)	Maternal blood (1 to 3 samples), umbilical cord blood and placental tissue: Mn	Pace of living, reported pesticide spraying <1 km, educational level, age, gender, smoking	Face-to-face interview	– <i>Mn blood levels</i> Living in urban and/or agricultural areas vs. living in a village (+) *, pesticide spraying <1 km from house (+) *	D
(Tao et al., 2019)	China, 2017, orchard workers families (N=275), kindergarten children, (N=247), urban residents (N=95)	Urines (1 sample): IMI and 6-CNA	School proximity to fields, gender, age	Questionnaires administered to parents	– <i>IMI and 6-CAN levels</i> Children schooling close to orchards (+) *	D

(+) positive associations; (-) negative associations; \* results from univariate statistical tests

Abbreviations: 6-CNA: 6-chloronicotinic acid, BMI: Body Mass Index, DAPs: Dialkyl phosphates, DCCA: *cis- and trans-3-(2,2-dichlorovinyl)-2,2-dimethyl-cyclopropane-1-carboxylic acid*, DCVA: *cis- and trans- 2,2-dichlorovinyl-3,3-dimethylcyclopropane-1-carboxylic acid*; DEAPs: Diethylalkylphosphates, DEP: diethyl phosphate, DMAPs: dimethylalkylphosphates, DMTP: dimethyl thiophosphate, GIS: Geographic Information System, IMI: Imidacloprid, Mn: Manganese, OP: Organophosphorus pesticides, PBA: 3-phenoxybenzoic acid; PNP: *p*-nitrophenol; PYR: Pyrethroids, u-ETU: urinary ethylenethiourea, TCP: 3,5,6-trichloropyridinol, THPI: *cis-1,2,3,6-tetrahydrophthalimide*

**Table 2 – Evidence for determinants of non-dietary exposure to agricultural pesticides linked to spray drift in people living close to fields in environmental monitoring studies (n=11)**

<b>Study reference</b>	<b>Location, Time period, Population</b>	<b>Exposure measurement</b>	<b>Determinants of exposure to agricultural pesticides studied</b>	<b>Measurement of exposure determinants</b>	<b>Determinants of exposure to pesticides (results from multivariate models)</b>	<b>Study score</b>
(Beranger et al., 2014)	France, 2012, homes <1000m from orchards, cereals or vineyards (N=203)	House dust: 64 agricultural pesticides	Crop acreage around home (wind-weighted or not), barriers (vegetative, topographic, structural), presence of pets, number of occupants	Face-to-face interview, GIS	– <i>Presence or levels of pesticides</i> Crop acreage (+), prevailing wind (+), barriers (-)	A
(Butler-Dawson et al., 2018)	USA, 2008-2011, agricultural (N=138) and non-agricultural families (N=140)	House dust (2 samples 1 year apart): azinphos-methyl, phosmet, malathion, chlorpyrifos	Residential proximity to fields or orchards <25m, window/door opening frequency, presence of ventilation, house cleaning frequency	Face-to-face interview	– <i>Azinphos-methyl and phosmet levels (in the non-agricultural household)</i> Living <25m from fields or orchards	B
(Gibbs et al., 2017)	USA, Washington State, 2011, farmworker (N=14) and non-farmworker (N=9) households	Polyurethane foam passive air samplers, polypropylene deposition plates: OP (chlorpyrifos, azinphos-methyl) and their oxygen analogs	Residential proximity to orchards ≤250m	GIS	– <i>Concentrations in outdoor air/Indoor air/ Surface deposition of OP and their oxygen analogs</i> Residential proximity to fields ≤ 250m (+) *	C
(Gunier et al., 2011)	USA, California, 2001-2006, homes where >25% of land area within 500m in fields (N=89)	House dust: carbaryl, chlorpyrifos, diazinon, phosmet, DCPA, simazine, iprodione	Agricultural use of pesticide near home (<500m; <1250m), season	Face-to-face interview, GIS	– <i>Chlorpyrifos, DCPA, iprodione, phosmet, and simazine levels</i> Pesticide use <1,250m from home during the past 365 days (+) – <i>Carbaryl levels</i>	B

Study reference	Location, Time period, Population	Exposure measurement	Determinants of exposure to agricultural pesticides studied	Measurement of exposure determinants	Determinants of exposure to pesticides (results from multivariate models)	Study score
					Season (fall>summer> spring>winter) (+)	
(Gunier et al., 2014)	USA, California, 1999-2000, residences, CHAMACOS cohort (N=465)	Dust (N=378 in the first sampling and N=90 in the second): Mn	Housing and population density (pers/room, pers/m <sup>2</sup> ), precipitations in the past weeks, elevation (m), Mn-fungicide use near home (500/1000/3000 m) in the past 2 months, Mn-fungicide use near home wind-weighted (<3000m), housekeeping quality, number of doormats	Face-to-face interview, GIS	– Concentrations or loading of Mn in dust collected at both visits Agricultural Mn fungicide use near home in past 4 weeks wind-weighted (+), Poor housekeeping (+)	B
(Harley et al., 2019)	USA, 2016, 14–16-year-old girls living in California (N=97)	Silicone wristbands worn for 1 week: 63 pesticides and related breakdown products	Residential proximity to fields <100m, observing sprayings from home, living in the city, window open at night, having carpets and doormats, house cleaning frequency	Face-to-face interview	– DCPA presence Carpet in home (+) *, living in the city (-) *, crops within 100 m of home (+) * – Permethrin presence Doormats (-) * – Esfenvalerate presence Window open at night (+) *, – Piperonyl butoxide presence Clean daily (-) *	A

Study reference	Location, Time period, Population	Exposure measurement	Determinants of exposure to agricultural pesticides studied	Measurement of exposure determinants	Determinants of exposure to pesticides (results from multivariate models)	Study score
(Harnly et al., 2009)	USA California, 1999-2000, residences, CHAMACOS cohort (N=168)	House dust (3 samples per dwelling): 14 OP, two PYR, and 4 other pesticides (iprodione, DCPA, vinchlozolin, methomyl)	Agricultural pesticide use near home for different periods, residential proximity to fields <60m, temperature and rainfall, housekeeping quality, having an air conditioner, housing density (pers/room)	Face-to-face interview, GIS	<ul style="list-style-type: none"> <li>- <i>Chlorpyrifos concentrations</i></li> <li>Agricultural pesticide use in past month (+), air conditioner in home (-)</li> <li>- <i>Diazinon concentrations</i></li> <li>Rainfall in last days (-), housing density <math>\geq 2</math> (+)</li> <li>- <i>DCPA concentrations</i></li> <li>Agricultural pesticide use in past month, season (+), living <math>\leq 60</math>m from fields (+), temperatures in past days, month and season (+), rainfall in last days, month, season (-), home less clean (+)</li> <li>- <i>Iprodione concentrations</i></li> <li>Agricultural pesticide use near home in past month/season (+)</li> <li>- <i>Trans-permethrin</i></li> <li>Air conditioner in home (+)</li> </ul>	B
(Hogenkamp et al., 2004)	Netherlands, homes <400m from bulb fields of farmers (N=12) and non-farmers (N=15)	House dust: chlorizadon, chloroprotham, metamidron, flutolanil procymidon, toclofos-methyl, vinchlozolin	Residential proximity to fields <20m	Checklist during sampling	<ul style="list-style-type: none"> <li>- <i>Chlorizadon, chloroprotham, flutolanil procymidon, toclofos-methyl</i></li> <li>No association</li> </ul>	C

Study reference	Location, Time period, Population	Exposure measurement	Determinants of exposure to agricultural pesticides studied	Measurement of exposure determinants	Determinants of exposure to pesticides (results from multivariate models)	Study score
(Hung et al., 2018)	Taiwan, 2016, pregnant women (N=56)	Indoor and outdoor dust: Carbamate (carbofuran), OP (chlorpyrifos, terbufos), PYR (cypermethrin, cyphenothrin, deltamethrin, permethrin, prallethrin, tetramethrin)	Season, presence of farms around home (25, 50, 100, 200m)	Face-to-face interview, GIS	- <i>Detection of chlorpyrifos outdoors</i> Farm within 50m and 100m (+) *	C
(Plascak et al., 2019)	USA, Washington State, 2011, families (N=99)	House dust (n=418): OP (azinphos-methyl, phosmet, malathion)	Orchard density around home	Face-to-face interview, GIS	- <i>Summed dimethyl OP concentrations</i> Increasing orchard density for the 750m and 1250m radius around home (-)	A
(Ward et al., 2006)	USA, Iowa, 1998–2000, homes of adults (N=112)	House dust (1 sample per home): 14 herbicides	Acres of corn and soybeans around home (< 100, 101–250, 251–500, 501–750m), distance from fields	GIS	- <i>Detection or concentrations of herbicides</i> Acreages of corn and soybean < 750m (+), Distance from fields (-)	A

(+) positive associations; (-) negative associations; \* results from univariate statistical tests

Abbreviations: DCPA: Dimethyl tetrachloroterephthalate, GIS: Geographic Information System, Mn: Manganese, OP: Organophosphorus pesticides, PYR: Pyrethroids

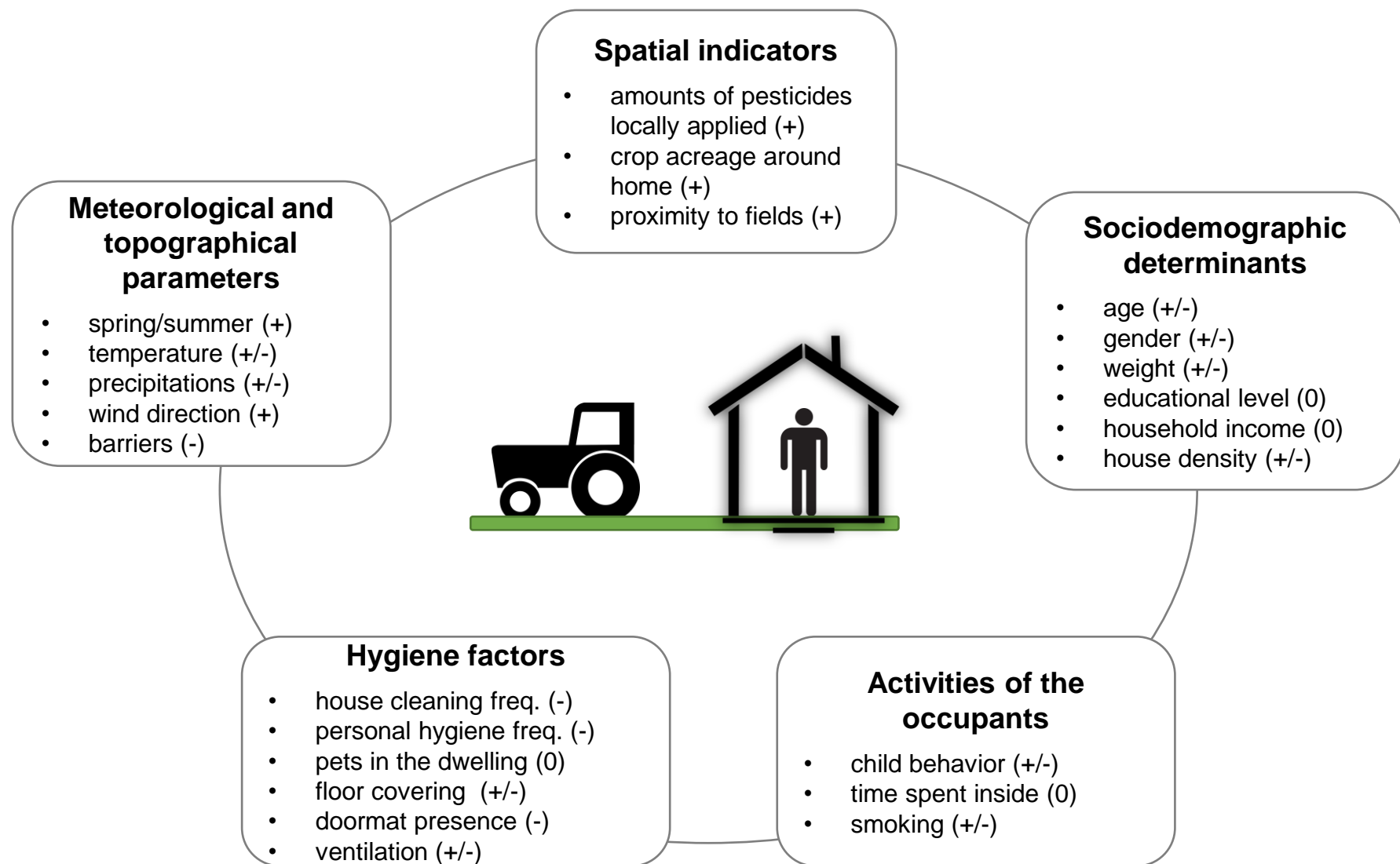
**Table 3– Evidence for determinants of non-dietary exposure to agricultural pesticides linked to spray drift in people living close to fields in environmental and bio-monitoring studies (n=3)**

Study reference	Location, Time period, Population	Exposure measurement	Determinants of exposure to agricultural pesticides studied	Measurement of exposure determinants	Determinants of exposure to pesticides (results from multivariate models)	Study score
(Coronado et al., 2011)	USA, Washington State, 2005-2006, farmworker and non-farmworker adults (N=200) and children (N=199)	Urines (3 samples): 3 OP metabolites (DMP, DMTP and DMDTP) House dust: azinphos-methyl and phosmet	Residential proximity to fields	Face-to-face interview, GIS	– <i>DMTP levels</i> Residential distance from fields (-)	A
(Glorennec et al., 2017)	France, 6-year-old children, PELAGIE cohort (N=245)	Urines: 5 PYR metabolites House dust: 5 PYR (cyfluthrin, cypermethrin, deltamethrin, permethrin, tetramethrin)	Crop acreages around home and school (<500m), house cleaning frequency	Self-administered questionnaire, GIS	– <i>Cis-DBCA, 3-PBA, Tetramethrin presence or levels</i> Crop acreages around home and school (+) – <i>Trans-DCCA and Cis-DCCA presence or levels</i> House cleaning ≥ 2/week (+)	B
(Siriwat et al., 2019)	Thailand, 2016, children aged 12-36 months living < 50m from fields (N=65)	Wipe samples on hands, feet, and surfaces (toys, beds, floors): chlorpyrifos Blood cholinesterase levels	Showers and hand washing frequency, house cleaning frequency, window opening frequency, children’s activities and behaviors	Face-to-face interview	– <i>Chlorpyrifos concentrations (feet)</i> Frequent hand washing (-), playing duration (-), sitting on floor, lying on wooden bed (-) – <i>Blood cholinesterase activity</i> House cleaning frequency (+)	C

(+) positive associations; (-) negative associations

Abbreviations: DBCA: *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid, DCCA: *cis*- and *trans*-3-(2,2-dichlorovinyl)-2,2-dimethyl-cyclopropane-1-carboxylic acid, DMP: dimethylphosphate, DMDTP: dimethyldithiophosphate, DMTP: dimethyl thiophosphate, GIS: Geographic Information System, OP: Organophosphorus pesticides, 3-PBA: 3-phenoxybenzoic acid; PNP: *p*-nitrophenol; PYR: Pyrethroids

# DETERMINANTS OF NON-DIETARY HUMAN EXPOSURE TO AGRICULTURAL PESTICIDES



Associations found in the scientific literature with the risk or the level of pesticide exposure:  
(+): positive associations, (-): negative associations (+/-): contradictory results, (0): no association