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1**Risk assessment of pesticide spray drift from citrus applications with air-blast sprayers in**

2**Spain**

3

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13

14Abstract

15

16There are not studies regarding risk assessment of pesticides in citrus grown in Spain. The aim of
17this study was to estimate the risks caused by worst-case drift scenarios from the principal
18pesticides used in this crop, in order to assess possible damage to the environment and human
19health. A field survey was performed to characterize the particular conditions of plant protection
20product applications to citrus in Spain. Six targets were identified to be the most affected by
21droplet spray drift in ours, and extensively in most Mediterranean conditions: water organisms,
22earthworms, bees, adult bystanders, child bystanders and residents. Three drift estimation models
23were used to assess the amount of drift at specific distances downwind of a field in order to
24calculate Risk Indicators. These showed safe conditions for earthworms and residents, but also
25indicated that some pesticides may pose risk to aquatic organisms, even with a 20 m buffer zone,
26bees, adult bystanders and child bystanders. In general, results generated similar consequences of
27hazard risk independently of the drift prediction model used, pointing out that toxicological data
28were more relevant for deducting the risks.

29

30Keywords: Buffer zone. Environmental risk. Bystander exposure. Drift models.

31

321. Introduction

33Control of pests, diseases and weeds in commercial crop production is a permanent concern for
34farmers because they produce important economic losses. In most of the cases, adequate control
35is achieved by applying plant protection products. The objective of these applications is to place
36the correct quantity of an active substance (a.s.) on a desired target, as efficiently and cost-
37effectively as possible, with minimal environmental impact. Although farmers and chemical
38industry are progressively required to exercise correct and careful use of these inputs, part of
39them are lost in the environment as a result of different processes, like run-off, leaching,
40evaporation and drift.

41Drift is recognised to be the most important source of diffuse environmental contamination (Jong
42et al., 2008; Maski and Durairaj, 2010). Spray drift is defined as the quantity of plant protection
43product that is carried out of the sprayed (treated) area by the action of air currents during the
44application process (ISO, 2005). Drifting material may take the form of droplet, dry particles or
45vapour and has potential effect on living organisms in areas adjacent to the treatment, particularly
46water surfaces, affecting nearby residents, bystanders, fauna and flora (Gil and Sinfort, 2005;
47Tsai et al., 2005). Thus, should be minimized as much as possible (Salyani and Farooq, 2004).
48In order to avoid undesirable effects of pesticides, the European Union adopted Regulation
491107/2009 (EC, 2009b) that rules the use and marketing of plant protection products. According
50to it, environmental pesticide damage should be assessed by means of environmental risk
51indicators. Conventionally the risk posed by plant protection products is estimated by a risk
52indicator (RI), which is the ratio of the estimated human exposure or predicted environmental
53concentration (PEC) to a toxicological reference value.

54Pesticide Occupational and Environmental Risk (POCER) indicators were developed by

55Vercruysse and Steurbaut (2002) following the OECD principles (OECD, 1997) for typical
 56agricultural conditions in Flanders (Belgium). The procedure is made up of one RI for each of the
 5710 targets described in Directive 91/414/EC (operators, workers, bystanders, aquatic organisms,
 58birds, earthworms, bees, beneficial arthropods, persistence in soil and leaching to groundwater)
 59(EC, 2009b). More recently, at European level, HARmonised environmental Indicators for
 60pesticide Risk (HAIR) have been developed, adding more modules and using different
 61toxicological reference values (Garreyn et al., 2007; Krujine et al., 2011).
 62RI should combine information on pesticide risk (hazard and exposure) with information on the
 63quantity and conditions of pesticide use. Moreover, Ramos et al. (2000) demonstrated the
 64importance of using region specific information when assessing pesticide risks to improve the
 65accuracy of such environmental risk assessment.
 66In order to estimate the exposure of a target to a particular drifted product, it is necessary to
 67assess the amount of drift generated during the treatment. This depends on the physicochemical
 68properties of the sprayed product and its a.s. (Holterman, 2003a; Holterman, 2003b; Stainier et
 69al., 2006; De Schamphelleire et al. 2009), the characteristics and geometry of the culture (foliage,
 70density, dimensions, etc.) (Belcher et al., 2003; Farooq and Salyani, 2004; Da Silva et al., 2006;
 71Yi, 2008), the machinery setup (sprayed volume, use of fans, tractor speed, etc.) (Walklate, 1992;
 72Farooq and Salyani, 2002; Delete et al 2005; Derksen et al. 2007; Nuyttens et al., 2011), the
 73meteorological conditions (wind, humidity, temperature, etc.) (Miller et al., 2000; Thistle, 2000;
 74Gil et al., 2007; Wang and Rautmann, 2008; Endalew et al., 2010), soil and water properties,
 75number of treatments, etc). All of them vary from country to country and must be taken into
 76account.
 77Estimation of the amount of spray drifted from a pesticide application is often based on German

78models (Ganzelmeier et al., 1995; Rautmann et al., 2001). These are based on experimental data
79obtained in different cultures grown in Central Europe (cereals, vines, fruit trees, etc) and
80describe worst case drift measurements in field crop applications in Germany, in terms of
81percentage of treatment deposited on the ground as a function of downwind distance to the edge
82of the field. Similarly, Holterman and van de Zande (2003) developed the so called IMAG drift
83calculator. They worked with potatoes, flower bulbs, sugar beets, cereals, bare soil, fruit trees in
84leaf and leafless fruit trees grown in Dutch conditions. However, both drift models have been
85established under Northern Europe conditions, which greatly differ from Mediterranean
86conditions, and particularly on fruit crops other than citrus.

87Accurate risk assessment of citrus treatments in Spain must adapt to the specificities and
88practices of growers in such conditions, which substantially differ from other cultures and
89countries. In this sense, Meli et al. (2003) estimated drift produced by treatments of citrus under
90Catania (Italy) conditions and concluded that Ganzelmeier's tables overestimated drift in their
91conditions. More research on drift from citrus applications had been conducted but in North
92America conditions (Salyani and Cromwell, 1992; Salyani and Farooq, 2004; Salyani et al.,
932007).

94Citrus production is economically significant in Spain. The country is the sixth major producer in
95the world and the first exporter of whole fruit for the fresh (not juice) market (FAO, 2008). More
96than 318385 ha of citrus were grown and more than 6.3 million tons were produced in 2009
97(MARM, 2009), which reveals the importance of accurate pesticide risk assessment in our
98conditions. However, there are not published works on assessment of risks caused by pesticide
99spray drift in this context

100On the other hand, European Directive 2009/128 (EC, 2009a) pays particular attention to

101avoiding pollution of surface water and groundwater by taking appropriate measures, particularly
102the establishment of buffer zones to reduce exposure of water bodies to spray drift. Buffer zones
103are adjacent strips of vegetation that do not receive pesticide applications. The width of buffer
104zones can be deducted from locations where acceptable risk indices are achieved (De
105Schampheleire et al., 2007).

106We also have to consider that citrus in Spain and other Mediterranean countries are mostly
107cultivated far away from surface water bodies but close to residential areas, so in these cases it is
108important to emphasize the risks to bystanders, child bystanders and residents.

109This work is aimed at estimating risks caused specifically by drift in Spanish citrus groves, and
110for this reason it is focused on ground foliar applications since they are main sources of drift
111compared to applications directed to the soil. Aerial applications are not considered because they
112are not employed in this area.

113In the first part of this work, spraying practices in Spain are characterized from data obtained
114from a survey. The second part assesses exposure to drift caused by such practices. Finally, risks
115caused to fauna, flora, adult bystanders, child bystanders (children are more vulnerable than
116adults so the risks are different) and residents are estimated. As a consequence, acceptable width
117of buffer zones is estimated.

118

1192. Materials and methods

1202.1. Characterization of foliar pesticide applications in the Spanish citrus regions

121To characterize current foliar pesticide applications in the Spanish citrus growing regions, 175
122surveys were performed by interviewing farmers and technicians from farmer associations or
123service companies in the more important Spanish citrus regions in 2004/2005.

124The area sampled was approximately 18000 ha, predominately planted with oranges (71.2%),
125followed by tangerines (26.1%) and lemons (2.7%).

126The survey was divided in two parts. The first part contained questions about the characteristics
127of the exploitation, the equipment used and its setup. The second part recorded each treatment
128during the season (plant protection products used, biological problems encountered, dates, spray
129volumes, operating parameters of each application, etc.).

130

1312.2. Estimation of the amount of drift

132In this study, German drift curves (Ganzelmeier et al., 1995; Rautmann et al., 2001), Dutch
133IMAG drift calculator (Holterman and van de Zande, 2003) and the model proposed by Meli
134(Meli et al., 2003) were used to predict the amount of pesticide drift at specific distances
135downwind from a given field.

136German drift models do not target citrus. They only distinguish between early applications of
137fruit trees, late applications, grape vine, hops and field crops. We considered data from late
138applications of fruit trees because we assumed that they would be closer to those of citrus. Dutch
139drift values distinguish between potatoes, flower bulb, sugar beets, cereals, bare soil, fruit trees in
140leaf and leafless fruit trees, so we used fruit trees in leaf data for our calculations. Meli's model is
141specific for citrus and air-blast sprayer and we used his data. However, tests were conducted from
1421.5 up to 7.5 m and then extrapolated out to 15 m by the authors. Consequently, the resulting
143curve is limited and almost constant at distances greater than 10 m.

144All of these models represent the percentage of applied dose that has drifted (*%drift*) as a
145function of the downwind distance from the end of the field (z). We assumed that all of them
146refer to the last row of trees as the initial reference point.

Equations (1), (2), (3) and (4) summarize these models:

German model

$$\%drift = 60.36 \times z^{-1.2243} \quad (z < 15 \text{ m}) \quad (1)$$

$$\%drift = 298.83 \times z^{-1.8672} \quad (z > 15 \text{ m}) \quad (2)$$

IMAG model

$$\%drift = 48 \times e^{\frac{-z}{2.7}} + 0.45 \times e^{\frac{-z}{0.091}}$$

$$(3)$$

Meli model

$$\%drift = 11.542 \times z^{-0.4026} \quad (4)$$

It can be deducted that all of them assume that in the first five meters drift decreases sharply and then decrease much more slowly (Fig. 1). Moreover, drift values significantly differ from model to model in these first five meters. German model assumes the highest values followed by IMAG and then Meli curves.

Fig. 1.

2.3. Assessment of risks

We assumed that drift from pesticide application mainly causes risks to neighbouring fields and residential areas, water surfaces or nature reserves. For this reason, we focused on targets that can be affected by droplet drift: aquatic organisms, earthworms in adjacent fields, bees, adult bystanders, child bystanders and residents. We did not consider birds, because indicators refer to damage caused by intake, nor beneficial arthropods, because RIs consider direct application of

170pesticide.

171RIs are individually calculated for every a.s.. These are different depending on the country and
172crop. We used the survey to generate a list of them that was checked against the official list of
173registered substances in Spain (MARM, 2011). The next step was to obtain their toxicological
174data from the European Commission Database (DG SANCO, 2011).

175The total amount of a.s. per unit surface is one of the parameters required to estimate the
176Predicted Environmental Concentration (PEC) and the exposition of bystanders. It is the product
177of the sprayed volume (from the surveys) by the concentration of the product and the percentage
178of a.s. in it. In all cases we considered the combination of concentration of plant protection
179product and percentage of a.s. that produced the maximum value.

1802.3.1. Aquatic organisms

181According to the POCER indicator, the predicted environmental concentration ($PEC_{Initial}$, mg/L)
182for aquatic organisms is estimated by Equation (5) (Vercruysse and Steurbaut, 2002). The factor
1831000 is a conversion factor for the units.

$$184 \quad PEC_{Initial} = \frac{(AR \times \%drift)}{(d_{ditch} \times 1000)}$$

185 (5)

186where AR is the application rate (kg a.s./ha), $\%drift$, the drift deposition (in %), d_{ditch} , ditch depth
187(0.5 m is the typical value for the area).

188The RI for aquatic organisms is calculated as the quotient of the $PEC_{Initial}$ and the endpoint for
189aquatic organisms. This endpoint is calculated from acute toxicity data of the three groups of
190organisms. The lowest of the following three quotients is used as the endpoint:

191* Fish: $LC_{50} / 100$

192where LC_{50} (mg/L) is the median lethal concentration, i.e. the concentration of a.s. that causes

193death to 50% of a test fish population.

194* Daphnia: $EC_{50} / 100$

195where EC_{50} (mg/L) is the median effect concentration, i.e. the concentration of a.s. that affects

19650% of a Daphnia (Daphnia spp. Leydig) test population.

197* Algae: $NOEC / 10$

198where $NOEC$ (mg/L) is the no observed effect concentration, which is the highest concentration

199of a.s. that causes no observable adverse effects on an algae test population.

200The safety factors used in the three previous equations are defined in the Uniform Principles (EC,
2012009b).

202

2032.3.2. Earthworms

204In this case, $PEC_{Initial}$ in soil (mg/kg soil) is estimated by Equation (6). To estimate it, pesticide is

205assumed to accumulate homogeneously in the top 5 cm of the soil (Vercruysse and Steurbaut,

2062002) and the drift deposition was added in the equation to consider the risk outside the applied

207area.

$$208 \quad PEC_{Initial} = \frac{(AR \times \%drift \times (1 - f))}{(d \times \rho)}$$

209 (6)

210where AR is the application rate (kg a.s./ha), $\%drift$, the drift deposition (in %), f , the fraction of

211deposited a.s. intercepted by crops (we considered the worst case scenario which is an area

212without crop, 0), d , soil layer depth (0.05 m, as stated before), ρ , soil density (the typical value for

213the Spanish citrus area is 1350 kg/m³).

214Then, RI for earthworms is calculated using Equation (7).

$$RI_{Earthworms} = \frac{PEC_{Initial}}{\frac{LC_{50}}{10}} \quad (7)$$

where LC_{50} is the acute median lethal concentration for earthworms (mg/kg soil). The factor 10 is a safety factor set by Uniform Principles (EC, 2009b).

2.3.3. Bees

A hazard quotient, defined as the ratio of the application rate of a pesticide's a.s. (g a.s./ha) to the acute LD_{50} (median lethal dose) (μ g a.s./bee) was used according to Vercruysse and Steurbaut (2002). RI is then calculated using Equation (8). Drift deposition was added in the equation to consider the risk outside the applied area. The factor 50 is the criteria set by Uniform Principles (EC, 2009b).

$$RI_{Bees} = \frac{AR \times \frac{\%drift}{100}}{(LD_{50} \times 50)} \times 1000$$

(8)

where AR is the application rate (kg a.s./ha), $\%drift$, the drift deposition (in %), LD_{50} , the minimum between $LD_{50 \text{ oral}}$ and $LD_{50 \text{ contact}}$ (μ g a.s./bee).

The factor 1000 is used to convert the application rate from kg a.s./ha to g a.s./ha, used for calculation of the hazard quotient. This quotient used here is different from the exposure toxicity ratio used in other indicators, since exposure and effect concentrations are not expressed in the same units (Krujine et al., 2011). These values cannot be compared to each other.

2.3.4. Adult bystanders

Adult bystanders are people located within or directly adjacent to the area where pesticide

application or treatment is in process or has taken place. Adult bystander exposure results from contact with spray drift during the pesticide treatment.

According to POCER, adult bystander dermal and inhalation exposure is estimated using Equations (9) and (10). It is assumed that bystanders are located 8 m downwind from the treated field, according to EUROPOEM (1996), that only ordinary clothing is worn and the total uncovered skin area (EA) amounts to 0.4225 m^2 (Vercruysse and Steurbaut, 2002).

$$DE_{Bys tan der} = AR \times \%drift \times EA \quad (9)$$

where $DE_{Bystander}$ is the adult bystander dermal exposure (mg/person/day), AR , application rate (kg a.s./ha), $\%drift$, the drift deposition (in %), EA , exposed area (0.4225 m^2 / person/day).

$$I_{Bys tan der} = \frac{I_a \times AR \times DED}{ST}$$

$$(10)$$

where $I_{Bystander}$ is the adult bystander inhalation exposure (mg/person/day), I_a , the applicator inhalation exposure (0.018 mg/kg a.s. according to Garreyn et al., 2007), AR , application rate (kg a.s./ha), ST , spraying time (min/ha), DED , daily exposure duration (min/day).

250

Daily exposure for applicators can be set at 6 hours per day, while inhalation exposure for adult bystanders is calculated at only 1 minute because they usually have only brief exposure to pesticide spray drift (Vercruysse and Steurbaut, 2002). Spraying time was obtained from the above mentioned interviews with farmers.

Adult bystander risks were assessed by comparing its exposure with AOEL (acceptable operator exposure level). RI for adult bystander is calculated using Equation (11). Bodyweight is assumed to be 70 kg by international standards.

$$RI_{Bystander} = \frac{(DE \times Ab_{DE} + I \times Ab_I)}{(BW \times AOEL)}$$

(11)

where $RI_{Bystander}$ is the risk indicator for adult bystanders, DE , the dermal exposure (mg/person/day), Ab_{DE} , the dermal absorption factor (0.1 according to Garreyn et al., 2007), I , the inhalation exposure (mg/person/day), Ab_I , the inhalation absorption factor (1.0 according to Garreyn et al., 2007), BW , body weight (70 kg by default), $AOEL$, acceptable operator exposure level (mg/kg bodyweight/day).

2.3.5. Child bystanders

The RI for child bystanders is a special case of the acute RI for adult bystanders because children are more vulnerable.

The total dermal exposure is calculated, according to Garreyn et al. (2007), by summing up the different types of dermal exposure (dermal exposure resulting from direct contact with spray drift, dermal exposure resulting from contact with a lawn contaminated by spray drift, dermal exposure resulting from ingestion of turf residues (hand-mouthing activity) and dermal exposure resulting from ingestion of turf residues(object-to-mouth exposure)) using Equations (12), (13), (14) and (15). All values in brackets are from Garreyn et al. (2007).

$$DE_{Child, direct} = AR \times \%drift \times EA_{Child}$$

(12)

where $DE_{Child, direct}$ is the dermal exposure to direct spray drift (mg/person/day), AR , application rate (kg a.s./ha), $\%drift$, the drift deposition at 8 m of distance (in %), EA_{Child} , exposed area of a child (0.2 m²/person/day).

$$DE_{Child, lawn} = 10^{-4} \times AR \times \%drift \times TTR_{Turf} \times TF \times DED_{Child}$$

(13)

where $DE_{Child, lawn}$ is the dermal exposure of a child by contact with drift reaching lawn (mg/person/day), AR , application rate (kg a.s./ha), $\%drift$, the drift deposition at 8 m of distance (in %), TTR_{Turf} , turf transferable residue value (0.05), TF , transfer factor (5200 cm²/h), DED_{Child} , daily exposure duration (2 h/day).

$$DE_{Child, turf} = 10^{-4} \times AR \times \%drift \times TTR_{Turf} \times SE \times EA_{Fingers} \times N_{Events} \times DED_{Child}$$

(14)

where $DE_{Child, turf}$ is the dermal exposure of child resulting from hand-mouth activity with turf (mg/person/day), AR , application rate (kg a.s./ha), $\%drift$, the drift deposition at 8 m of distance (in %), TTR_{turf} , turf transferable residue value (0.05), SE , saliva extraction factor (0.50), $EA_{Fingers}$, exposed area of fingers (20 cm²), N_{events} , number of hand-to-mouth exposure events per hour (20 events/hour), DED_{Child} , daily exposure duration (2 h/day).

$$DE_{Child, object} = 10^{-4} \times AR \times \%drift \times TTR_{Object} \times IgR$$

(15)

$DE_{Child, object}$ is the dermal exposure of child resulting from ingestion of turf residues (mg/person/day), AR , application rate (kg a.s./ha), $\%drift$, the drift deposition at 8 m of distance (in %), TTR_{Object} , object transferable residue value (0.20), IgR , ingestion rate (25 cm² grass/day). Inhalation exposure and risk indicator of children exposed as bystanders are assessed in the way outlined for bystanders (Equations (10) and (11)). Bodyweight is assumed to be 15 kg.

300

12.3.6. Residents

The RI for residents describes the exposure of people living nearby fields. Exposure near a field

occurs through dermal exposure to spray drift (Equation (16)) and through inhalation of vapour originating on the field (Equation (17)). Residents are assumed to be located at 50 m of distance downwind from the treated field (Garreyn et al., 2007; Krujine et al., 2011). The drift values were taken only from the German tables, because the other two models do not predict drift at this distance. Only for assessing resident risks, the 77th percentile was used for drift value for three applications per year, the 82th percentile was used for two applications per year and 90th percentile for one application per year, according Garreyn et al. (2007). The indicator for residents is calculated for multiple applications, and is therefore chronic in nature. The frequency of applications yearly for each a.s. and spraying time were obtained in the field survey. It was used the maximum number of applications per year.

$$DE_{Residents} = AR \times \%drift \times FA \times EA \times \frac{RD}{365}$$

(16)

where $DE_{Residents}$ is the dermal exposure (mg/person/day), AR , application rate (kg a.s./ha), $\%drift$, the drift deposition at 50 m of distance (in %), FA , frequency of applications, EA , exposed area (0.4225 m²/ person/day), RD , residence days (90 days according to Garreyn et al., 2007).

$$I_{Residents} = \frac{I_a \times AR \times DED}{ST} \times EF \times YED \quad (17)$$

where $I_{Residents}$ is the inhalation exposure (mg/person/day), AR , application rate (kg a.s./ha), ST , spraying time (min/ha) and the following data in brackets are from Garreyn et al. (2007): I_a , the applicator inhalation exposure (0.018 mg/kg a.s.), DED , daily exposure duration (480 min/day), EF , exposure frequency (3 months/12 months = 0.25) and YED , yearly exposure duration (1.0). Residence risks were assessed by comparing its exposure with AOEL (acceptable operator exposure level) (Equation (18)).

$$RI_{Residents} = \frac{(DE_{Residents} \times Ab_{DE} + I_{Residents} \times Ab_I)}{(BW \times AOEL)}$$

(18)

where $RI_{Residents}$ is the RI for residents, $DE_{Residents}$, the dermal exposure (mg/person/day), Ab_{DE} , the dermal absorption factor (0.1 according to Garreyn et al., 2007), $I_{Residents}$, the inhalation exposure (mg/person/day), Ab_I , the inhalation absorption factor (1.0 according to Garreyn et al., 2007), BW , body weight (70 kg), $AOEL$, acceptable operator exposure level (mg/kg bodyweight/day). Because the last tree row is typically placed at 3 m distance from the field edge in order to allow tractor displacement, we calculated risk indicators for water organisms, earthworms and bees at 3 m downwind, because this represents the worst case scenario. By considering risk indices at different distances downwind from the field, it was possible to define the minimum width of a buffer zone needed to avoid the risk of pesticide drift.

3. Results and discussion

3.1. Characterization of foliar pesticide applications in the Spanish citrus regions

Interviews showed that farms between 1 and 10 ha prevailed and were basically managed by their owners, however technicians managed larger farmers, specially those with more than 50 ha. In any case trees were around 6-20 years old and spacing was 4.5-6 m by 3-6m.

Air-blast sprayers were the most common machines employed (58%) in foliar applications, followed by hand-held gun hydraulic sprayers (42%). With regard to the age of the equipment, 65% of the air-blast sprayers were less than 5 years old while 75% of gun sprayers were over 5 years old. This difference is due to increasing labour costs, which results in farmers relying progressively on more mechanised applications. Because this trend has been accentuated in the last few years, and air-blast sprayers produce more drift than gun sprayers (Meli et al., 2003), we

348will use only data from air-blast sprayer treatments in the risk assessment part of this work.

349The main operational characteristics of air-blast sprayers are shown in Table 1. According to the
350interviews, foliar applications from air-blast sprayers cover 7.4 ha per day. An average spraying
351time of 70 minutes per hectare was used to calculate pesticide inhalation risk. Applications are
352normally performed in spring and in the end of summer. Some applications for lemon trees are
353also scheduled in July. Insecticides are the most widely used products for oranges and tangerines
354and account for 50% of all treatments, followed by foliar fertilizers and plant growth regulators
355(20%), acaricides (10%) and fungicides (10%). For lemons, insecticide applications represent
35660% of treatments and the remaining 40% correspond to acaricide applications.

357

358Table 1.

359

360Table 2 lists the primary a.s. used in citrus areas of Spain.

361

362Table 2.

363

364The 90th percentile values of spray volumes reported in the questionnaires were calculated to use
365them in risk assessment, considering that they provide the worst-case scenario. Following this
366reasoning, a spray volume of 1977 L/ha was considered for fungicides and plant growth
367regulators, and 4016 L/ha for insecticides and acaricidas. For abamectin, a spray volume of 3500
368L/ha was used, because this is the maximum permitted by Spanish legislation. These regulations
369do not specify a maximum spray volume for the other products.

370In Spain, labels indicate the concentration of plant protection product in the tank, but farmers and

371 technicians determine spray volume, and consequently, the amount of product applied per unit
372 area. Increasing spray volume while maintaining pesticide concentration leads to significant
373 increases in risk given that the amount of chemical applied per unit area is an important
374 component in predictive models of environmental risk.

375

376 3.2. Assessment of risks

377 3.2.1. Aquatic organisms, earthworms and bees

378 RIs corresponding to water organisms, earthworms and bees that are calculated using predicted
379 drift at 3 m, resulted in the same conclusion, independently of the drift model chosen (Tables 3
380 and 4) although predicted drift percentages are different. This is due to the fact that toxicological
381 data have more weight in the calculation of RIs than drift values. This demonstrates the
382 importance of pesticide manufacturing industry to investigate new products with low risks and
383 farmers to seek after safer pesticides.

384

385 Table 3.

386

387 Table 4.

388

389 According to Vercruysse and Steurbaut (2002), RI less than one is considered safe while greater
390 than one indicates risk. Aquatic organisms 3 m away from the field may be at risk when applying
391 abamectin, chlorpyrifos, cooper oxychloride, mancozeb, pyriproxyfen or tebufenpyrad because
392 the values of RI were higher than one. Moreover, even with a 20 m buffer zone, aquatic
393 organisms may be still at risk, except for pyriproxyfen in the three drift models and mancozeb

394and tebufenpirad in the IMAG model. In these cases, it would be necessary to employ drift
395mitigation techniques, such as low-drift nozzles, adjuvants, etc. Precise adjustment of spray
396volumes would also be helpful. On the other hand, fosetyl-aluminium, gibberellic acid,
397hexythiazox and 2,4-D would not require the establishment of buffer zones.

398Ansara-Ross et al. (2008) also reported that abamectin is highly toxic to aquatic organisms.
399Concentrations in the water, however, are expected to be low mainly due to photodegradation and
400adsorption of this pesticide by sediments. It is also rapidly degraded by soil micro-organisms and
401becomes less toxic to aquatic organisms. In addition, Hernández-Hernández et al. (2007)
402discussed the high risk of mancozeb drift for aquatic life. The United States Environmental
403Protection Agency (EPA, 2002) also cites the risk of chlorpyrifos for aquatic life and suggests
404constant monitoring in areas where it is used. This high risk is due to the low concentrations at
405which Daphnia spp. are affected and the high doses used in the study area. Copper-based
406fungicides have been shown to affect a variety of aquatic organisms (Oliveira-Filho et al., 2004).
407Calculated RIs indicate that buffer zones differ in size depending on the model used to estimate
408drift for pyriproxyfen. Its application could be considered safe if a 7 to 11 m buffer zone is kept.
409When RIs are very high it is not possible to define the minimum width of a buffer zone, because
410this zone is not sufficient to mitigate the risks. It would be important to have a specific citrus drift
411model usable to at least 20 m downwind from a field.

412It can be seen that RIs for earthworms at 3 m are lower than 1, regardless of the model used. This
413means that none of the products are supposed to constitute a hazard for earthworms in the
414surroundings of the fields.

415According to all three drift models bees at 3 m have RIs higher than 1 for abamectin and
416chlorpyrifos. We have to highlight this because honey bees are also a source of income to some

growers. Moreover, these pollinators are considered essential for almost all terrestrial ecosystems including those dominated by agriculture and are excellent indicators of environmental pollution (Thompson, 2003). Chlorpyrifos is acutely toxic to honey bees, consequently, its application would be expected to pose a risk to bees and beneficial insects in the area under application (EPA, 2002).

2.2 Human exposure

Calculated RIs for the majority of the products are lower than 1 for adult bystanders and child bystanders (Table 4), and are considered safe. The exceptions are Mancozeb, which may pose a risk to child bystanders in German and Meli models ($RI > 1$), and Chlorpyrifos which produced RIs higher than 1 for child bystanders in all models and for adult bystanders, in German and Meli models. It is important to remark that exposures of child and adult bystanders can be significantly higher due to measurement positions closer than 8 m (Butler Ellis et al., 2010).

RIs for residents at 50 m are lower than 1, regardless of the model employed (Table 5).

Compared to the occupational exposure of applicators and bystanders, post-application resident exposure to pesticides used around their home is much lower. This is due to the greater distance to the orchard. However, resident exposure depends on a wider range of factors. Apart from exposure to pesticide drift, residents are exposed to pesticides into their homes on clothing or shoes after walking over treated surfaces (Garreyn et al., 2007). Moreover, RIs are calculated for each pesticide individually and there are not any procedure to assess risk associated to the combination of all applied products.

Table 5.

4. Conclusions

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441De Schamphelleire et al. (2007) did a similar work by evaluating various pesticides used on
442winter barley, potatoes, sugar beets and dwarf apples in Flanders. They did not found risks for
443earthworms and adult bystanders, but for water organisms. These results are similar than ours in
444citrus crop. We have not found in our study risks for earthworms but some pesticide formulations
445used in fruit orchards posed risks to water organisms(abamectin, chlorpyrifos, cooper
446oxychloride, mancozeb, pyriproxyfen and tebufenpyrad) . Moreover, we have also studied risk to
447child bystanders, residents and bees that were not considered by these authors, since they are
448more important in applications to citrus in Spain. We did not found risks for residents but child
449and adult bystander and bees may be at risk when applying chlorpyrifos and child bystander also
450with mancozeb and bees with abamectine. For this reason, the present work reaches the objective
451of providing RI values specifically produced by drift of the most used pesticides in Spanish citrus
452orchards and serves as a first step to determine acceptable width of buffer zones in our country
453that can be extrapolated to many other Mediterranean regions.

454This approach could be also useful to farmers as a rapid screening tool to help evaluate the
455environmental impacts of pest management strategies and pesticide choices. Furthermore, this
456study highlights the necessity of investigating new products with low risks by manufacturing
457industry and using drift reduction techniques.

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467**References**

468

469Ansara-Ross, T.M., Wepener, V., Van den Brink, P.J., Ross, M.J., 2008. Probabilistic risk
470assessment of the environmental impacts of pesticides in the Crocodile (west) Marico catchment,
471North-West Province. Water SA 34, 637-45.

472Belcher, S.E., Jerram, N., Hunt, J.C.R., 2003. Adjustment of a turbulent boundary layer to a
473canopy of roughness elements. J. Fluid Mech 488, 369-398.

474Butler Ellis, M.C., Lane, A.G., O’Sullivan, C.M., Miller, P.C.H., Glass, C.R., 2010. Bystander
475exposure to pesticide spray drift: New data for model development and validation. [Biosystems](#)
476[Eng.](#) 107, 162-8.

477Da Silva, A., Sinfort, C., Tinet, C., Pierrot, D., Huberson, S., 2006. A lagrangian model for spray
478behaviour within vine canopies. Aerosol Science 37, 658-674.

479De Schamphelaire, M., Spanoghe, P., Brusselmann, E., Sonck, S., 2007. Risk assessment of
480pesticide spray drift damage in Belgium. Crop Prot. 26, 602-11.

481De Schamphelaire, M., Nuyttens, D., Baetens, K., Cornelis, W., Gabriels, D., Spanoghe, P., 2009.
482Effects on pesticide spray drift of the physicochemical properties of the spray liquid. Precision
483Agriculture. 10(5), 409-420.

484Delele, M.A., De Moor, A., Sonck, B., Ramon, H., Nicolai, B.M., Verboven, P., 2005. Modelling
485and validation of the air flow generated by a cross flow air sprayer as affected by travel speed and
486fan speed. *Biosystems Engineering* 92, 165-174.

487Derksen, R.C., Zhu, H., Fox, R.D., Brazee, R.D., Krause, C.R., 2007. Coverage and drift
488produced by air induction and conventional hydraulic nozzles used for orchard applications.
489Transactions of the ASABE 50, 1493-1501.

490DG SANCO, 2011. EU Pesticides database. Available at
491<http://ec.europa.eu/sanco_pesticides/public/index.cfm> (accessed on 5.4.2011).

492EC, 2009a. Directive 2009/128/EC of the European parliament and the council of 21 October
4932009 establishing a framework for community action to achieve the sustainable use of pesticides.
494Off. J. Eur. Un. L 309, 71-86.

495EC, 2009b. Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21
496October 2009 concerning the placing of plant protection products on the market and repealing
497Council Directives 79/117/EEC and 91/414/EEC. Off. J. Eur. Un. L 309, 1-50.

498Endalew, A.M., Debaer, C., Rutten, N., Vercammen, J., Delele, M.A., Ramon, H., Nicolai, B.M.,
499Verboven, P., 2010. A new integrated CFD modelling approach towards air-assisted orchard
500spraying. Part I. Model development and effect of wind speed and direction on sprayer airflow.
501Computers and Electronics in Agriculture 71,128-136.

502EPA, 2002. United States Environmental Protection Agency, Interim reregistration eligibility
503decision for chlorpyrifos. Available at
504<http://www.epa.gov/oppsrrd1/REDs/chlorpyrifos_ired.pdf> (accessed on 7.21.2011).

505EUROPOEM, 1996. The development, maintenance and dissemination of a European Predictive
506Operator Exposure Model (EUROPOEM) Database, final report. BIBRA International,
507Carshalton, UK.

508FAO, 2008. Food and agricultural commodities production. Available at
509<<http://faostat.fao.org/site/339/default.aspx>> (accessed on 7.14.2011).

510Farooq, M., Salyani, M., 2002. Spray penetration into the citrus tree canopy from two air-carrier
511sprayes. Transactions of the ASAE 45, 1287-1293.

512Farooq, M., Salyani, M., 2004. Modeling of spray penetration and deposition on citrus tree
513canopies. Transactions of ASAE 47, 619-627.

514Ganzelmeier, H., Rautmann, D., Spangenberg, R., Streloke, M., Herrmann, M., Wenzelburger,
515H.J., 1995. Studies on the spray drift of plant protection products. Blackwell Wissenschafts,
516Verlag GmbH, Berlin.

517Garreyn, F., Vagenende, B., Steurbaut, W., 2007. Harmonized environmental indicators for
518pesticides risk occupational indicators: operator, workers and bystander. Report financed by the
519EU sixth Framework Programme, contract number SSPEC-CT-2003-501977. HAIR, Ghent.

520Gil, Y., Sinfort, C., 2005. Emission of pesticides to the air during sprayer application: A
521bibliographic review. Atmos. Environ. 39, 5183-93.

522Gil, Y., Sinfort, C., Brunet, Y., Polveche, V., Bonicelli, B., 2007. Atmospheric loss of pesticides
523above an artificial vineyard during air-assisted spraying. Atmospheric Environment 41, 2945-
5242957.

525Hernández-Hernández, C.N.A., Valle-Mora, J., Santiesteban-Hernandez, A., Bello-Mendoza, R.,
5262007. Comparative ecological risks of pesticides used in plantation production of papaya:
527application of the SYNOPS indicator. Sci. Total Environ. 381, 112-25.

528Holterman, H.J., 2003a. Kinetics and evaporation of water drops in air. IMAG report 2003-12.
529Wageningen UR.

530Holterman, H.J., 2003b. Statistics of spray deposition and drift for inhomogeneous suspensions.
531p. 1–8. In: Proc. ILASS Conference. Sorrento, Italy, 13–17 July 2003.

532Holterman, H.J., van de Zande, J.C., 2003. IMAG Draft Report, IMAG Drift Calculator v1.1
533User manual. Available at <<http://idc.holsoft.nl>> (accessed on 11.4.2011).

534ISO, 2005. ISO/FDIS 22866, Equipment for crop protection - Methods for field measurement of
535spray drift. ISO, Geneva.

536Jong, F.M.W., Snoo, G.R., van de Zande, J.C., 2008. Estimated nationwide effects of pesticide
537spray drift on terrestrial habitats in the Netherlands. J. Environ. Manage. 86, 721-30.

538Kruijne, R., Deneer, J., Lahr, J., Vlaming, J., 2011. HAIR2010 Documentation, Calculating risk
539indicators related to agricultural use of pesticides within the European Union. Alterra,
540Wageningen.

541MARM, 2009. Ministerio de Medio Ambiente y Medio Rural y Marino, Anuario de Estadística
5422009. Available at <[http://www.marm.es/es/estadistica/temas/anuario-de-estadistica/2009/](http://www.marm.es/es/estadistica/temas/anuario-de-estadistica/2009/default.aspx)
543default.aspx> (accessed on 4.15.2011).

544MARM, 2011. Ministerio de Medio Ambiente y Medio Rural y Marino, Registro de productos
545fitosanitarios. Available at <<http://www.marm.es/es/agricultura/temas/default.aspx>> (accessed on
54610.15.2011).

547Maski, D., Durairaj, D., 2010. Effects of charging voltage, application speed, target height, and
548orientation upon charged spray deposition on leaf abaxial and adaxial surfaces. Crop Prot. 29,
549134-41.

550Meli, S.M., Renda, A., Nicelli, M., Capri, E., 2003. Studies on pesticide spray drift in a
551Mediterranean citrus area. *Agronomie* 23, 667-72.

552Miller, D.R., Stoughton, T.E., Steinke, W.E., Huddleston, E.W., Ross, J.B., 2000. Atmospheric
553stability effects on pesticide drift from an irrigated orchard. *Transactions of the ASAE* 43, 1057-
5541066.

555Nuyttens, D., De Schampheleire, M., Baetens, K., Brusselman, E., Dekeyser, D., Verboven, P.,
5562011. Drift from field crop sprayers using an integrated approach: results of a five-year study.
557Trans. ASABE 54, 403-8.

558OECD, 1997. Report of the OECD workshop on pesticide risk indicators. Available at
559<<http://www.oecd.org/dataoecd/24/24/2076771.pdf>> (accessed on 11.4.2011).

560Oliveira-Filho, E., Lopes, R.M., Paumgartten, F.J.R., 2004. Comparative study on the
561susceptibility of freshwater species to copper-based pesticides. *Chemosphere* 56, 369-74.

562Ramos, C., Carbonell, G., Garcia Baudín, J.M., Tarazona, J.V., 2000. Ecological risk assessment
563of pesticides in the Mediterranean region. The need for crop-specific scenarios. *Sci. Total*
564*Environ.* 247, 269-78.

565Rautmann, D., Streloke, M., Winkler, R., 2001. New basic drift values in the authorisation
566procedure for plant protection products, in Forster, R., Streloke, M. (Eds.), *Workshop on risk*
567*assessment and risk mitigation measures in the context of the authorisation of plant protection*
568*products (WORMM)*. Mitt. Biol. Bundesanst. Land-Forstwirtschaft, Berlin, pp. 133-41.

569Salyani, M., Cromwell, R.P., 1992. Spray drift from ground and aerial applications. *Trans. ASAE*
57035, 1113-20.

571Salyani, M., Farooq, M., 2004. Drift potential of citrus air-carrier sprayers. *Proc. Fla. State Hort.*
572*Soc.* 117, 130-5.

573Salyani, M., Farooq, M., Sweeb, R., 2007. Mass balance of citrus spray applications. ASABE
574Annual International Meeting. Paper number: 071037.

575Stainier, C., Destain, M.F., Schiffers, B., Lebeu, F., 2006. Droplet size spectra and drift effect of
576two phenmedipham formulations and four adjuvants mixtures. Crop Protection 25, 1238-1243.

577Thistle, H.W., 2000. The role of stability in fine pesticide droplet dispersion in the atmosphere: a
578review of physical concepts. Transactions of ASAE 43, 1409-1413.

579Thompson, H.M., 2003. Behavioural effects of pesticides in bees — their potential for use in risk
580assessment. Ecotoxicology 12, 317-30.

581Tsai, M., Elgethun, K., Ramaprasad, J., Yost, M.G., Felsot, A.S., Herbert, V.R., Fenske, R.A.,
5822005. The Washington aerial spray drift study: Modeling pesticide spray drift deposition from an
583aerial application. Atmos. Environ. 39, 6194-203.

584Vercruysse, F., Steurbaut, W., 2002. POCER, the pesticide occupational and environmental risk
585indicator. Crop Prot. 21, 307-15.

586Walklate, P.J., 1992. A simulation study of pesticide drift from an air-assisted orchard sprayer.
587Journal of Agricultural Engineering Research 51, 263-283.

588Wang, M., Rautmann, D., 2008. A simple probabilistic estimation of spray drift-Factors
589determining spray drift and development. Environmental Toxicology and Chemistry 27, 2617-
5902626.

591Yi, C., 2008. Momentum transfer within canopies. Journal of applied meteorology and
592climatology 47, 262-275.

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594 Fig. 1. Spray drift prediction based on different methodologies used for the pesticide risk
595 assessment.

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