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

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Abstract

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

Keywords: Buffer zone. Environmental risk. Bystander exposure. Drift models.
321. Introduction

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

Drift is recognised to be the most important source of diffuse environmental contamination (Jong et al., 2008; Maski and Durairaj, 2010). Spray drift is defined as the quantity of plant protection product that is carried out of the sprayed (treated) area by the action of air currents during the application process (ISO, 2005). Drifting material may take the form of droplet, dry particles or vapour and has potential effect on living organisms in areas adjacent to the treatment, particularly water surfaces, affecting nearby residents, bystanders, fauna and flora (Gil and Sinfort, 2005; Tsai et al., 2005). Thus, should be minimized as much as possible (Salyani and Farooq, 2004).

In order to avoid undesirable effects of pesticides, the European Union adopted Regulation 1107/2009 (EC, 2009b) that rules the use and marketing of plant protection products. According to it, environmental pesticide damage should be assessed by means of environmental risk indicators. Conventionally the risk posed by plant protection products is estimated by a risk indicator (RI), which is the ratio of the estimated human exposure or predicted environmental concentration (PEC) to a toxicological reference value. Pesticide Occupational and Environmental Risk (POCER) indicators were developed by
Vercruysse and Steurbaut (2002) following the OECD principles (OECD, 1997) for typical agricultural conditions in Flanders (Belgium). The procedure is made up of one RI for each of the 10 targets described in Directive 91/414/EC (operators, workers, bystanders, aquatic organisms, birds, earthworms, bees, beneficial arthropods, persistence in soil and leaching to groundwater). More recently, at European level, HArmonised environmental Indicators for pesticide Risk (HAIR) have been developed, adding more modules and using different toxicological reference values (Garreyn et al., 2007; Krujine et al., 2011).

RI should combine information on pesticide risk (hazard and exposure) with information on the quantity and conditions of pesticide use. Moreover, Ramos et al. (2000) demonstrated the importance of using region specific information when assessing pesticide risks to improve the accuracy of such environmental risk assessment.

In order to estimate the exposure of a target to a particular drifted product, it is necessary to assess the amount of drift generated during the treatment. This depends on the physicochemical properties of the sprayed product and its a.s. (Holterman, 2003a; Holterman, 2003b; Stainier et al., 2006; De Schampheleire et al. 2009), the characteristics and geometry of the culture (foliage, density, dimensions, etc.) (Belcher et al., 2003; Farooq and Salyani, 2004; Da Silva et al., 2006; Yi, 2008), the machinery setup (sprayed volume, use of fans, tractor speed, etc.) (Walklate, 1992; Farooq and Salyani, 2002; Delete et al 2005; Derksen et al. 2007; Nuyttens et al., 2011), the meteorological conditions (wind, humidity, temperature, etc.) (Miller et al., 2000; Thistle, 2000; Gil et al., 2007; Wang and Rautmann, 2008; Endalew et al., 2010), soil and water properties, number of treatments, etc.). All of them vary from country to country and must be taken into account.

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

Accurate risk assessment of citrus treatments in Spain must adapt to the specificities and practices of growers in such conditions, which substantially differ from other cultures and countries. In this sense, Meli et al. (2003) estimated drift produced by treatments of citrus under Catania (Italy) conditions and concluded that Ganzelmeier’s tables overestimated drift in their conditions. More research on drift from citrus applications had been conducted but in North America conditions (Salyani and Cromwell, 1992; Salyani and Farooq, 2004; Salyani et al., 2007).

Citrus production is economically significant in Spain. The country is the sixth major producer in the world and the first exporter of whole fruit for the fresh (not juice) market (FAO, 2008). More than 318,385 ha of citrus were grown and more than 6.3 million tons were produced in 2009 (MARM, 2009), which reveals the importance of accurate pesticide risk assessment in our conditions. However, there are not published works on assessment of risks caused by pesticide spray drift in this context.

On the other hand, European Directive 2009/128 (EC, 2009a) pays particular attention to
avoiding pollution of surface water and groundwater by taking appropriate measures, particularly
the establishment of buffer zones to reduce exposure of water bodies to spray drift. Buffer zones
are adjacent strips of vegetation that do not receive pesticide applications. The width of buffer
zones can be deducted from locations where acceptable risk indices are achieved (De
Schampheleire et al., 2007).

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

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

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

2. Materials and methods

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

To characterize current foliar pesticide applications in the Spanish citrus regions, surveys were performed by interviewing farmers and technicians from farmer associations or service companies in the more important Spanish citrus regions in 2004/2005.
The area sampled was approximately 18000 ha, predominately planted with oranges (71.2%), followed by tangerines (26.1%) and lemons (2.7%).

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

2.2. Estimation of the amount of drift

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

German drift models do not target citrus. They only distinguish between early applications of fruit trees, late applications, grape vine, hops and field crops. We considered data from late applications of fruit trees because we assumed that they would be closer to those of citrus. Dutch drift values distinguish between potatoes, flower bulb, sugar beets, cereals, bare soil, fruit trees in leaf and leafless fruit trees, so we used fruit trees in leaf data for our calculations. Meli’s model is specific for citrus and air-blast sprayer and we used his data. However, tests were conducted from 1.5 up to 7.5 m and then extrapolated out to 15 m by the authors. Consequently, the resulting curve is limited and almost constant at distances greater than 10 m.

All of these models represent the percentage of applied dose that has drifted (%drift) as a function of the downwind distance from the end of the field (z). We assumed that all of them refer to the last row of trees as the initial reference point.
Equations (1), (2), (3) and (4) summarize these models:

**German model**

\[ 149 \% \text{drift} = 60.36 \times z^{-1.2243} \quad (z < 15 \text{ m}) \]  
\[ 150 \% \text{drift} = 298.83 \times z^{-1.8672} \quad (z > 15 \text{ m}) \]  

**IMAG model**

\[ 152 \% \text{drift} = 48 \times e^{\frac{-z}{2.7}} + 0.45 \times e^{\frac{-z}{0.091}} \]  

**Meli model**

\[ 155 \% \text{drift} = 11.542 \times z^{-0.4026} \]  

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
pesticide.

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

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

2.3.1. Aquatic organisms

According to the POCER indicator, the predicted environmental concentration (PEC_{Initial}, mg/L) for aquatic organisms is estimated by Equation (5) (Vercruysse and Steurbaut, 2002). The factor 1000 is a conversion factor for the units.

\[
PEC_{Initial} = \frac{(AR \times %drift)}{(d_{ditch} \times 1000)}
\]

(5)

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

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

* Fish: LC_{50}/100

where LC_{50} (mg/L) is the median lethal concentration, i.e. the concentration of a.s. that causes
death to 50% of a test fish population.

* Daphnia: EC$_{50}$/100

where EC$_{50}$ (mg/L) is the median effect concentration, i.e. the concentration of a.s. that affects 50% of a Daphnia (Daphnia spp. Leydig) test population.

* Algae: NOEC/10

where NOEC (mg/L) is the no observed effect concentration, which is the highest concentration of a.s. that causes no observable adverse effects on an algae test population.

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

2.3.2. Earthworms

In this case, PEC$_{Initial}$ in soil (mg/kg soil) is estimated by Equation (6). To estimate it, pesticide is assumed to accumulate homogeneously in the top 5 cm of the soil (Vercruysse and Steurbaut, 2002) and the drift deposition was added in the equation to consider the risk outside the applied area.

\[
P_{EC_{Initial}} = \frac{(AR \times %drift \times (1 - f))}{(d \times \rho)}
\]  

(6)

where $AR$ is the application rate (kg a.s./ha), $%drift$, the drift deposition (in %), $f$, the fraction of deposited a.s. intercepted by crops (we considered the worst case scenario which is an area without crop, 0), $d$, soil layer depth (0.05 m, as stated before), $\rho$, soil density (the typical value for the Spanish citrus area is 1350 kg/m$^3$).

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

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

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

$$DE_{Bystander} = AR \times \%drift \times EA \quad (9)$$

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).

$$I_{Bystander} = \frac{I_a \times AR \times DED}{ST} \quad (10)$$

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).

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.
\[ RI_{\text{Bystander}} = \frac{(DE \times Ab_{DE} + I \times Ab_I)}{(BW \times AOEL)} \]  

(11)

where \( RI_{\text{Bystander}} \) 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).

\[ DE_{\text{Child, direct}} = AR \times \%\text{drift} \times EA_{\text{Child}} \]  

(12)

where \( DE_{\text{Child, direct}} \) is the dermal exposure to direct spray drift (mg/person/day), \( AR \), application rate (kg a.s./ha), \( \%\text{drift} \), the drift deposition at 8 m of distance (in %), \( EA_{\text{Child}} \), exposed area of a child (0.2 m\(^2\)/person/day).
280 \( \text{DE}_{\text{Child, lawn}} = 10^{-4} \times AR \times \%\text{drift} \times \text{TTR}_{\text{turf}} \times TF \times \text{DED}_{\text{Child}} \)

281 (13)

where \( \text{DE}_{\text{Child, lawn}} \) is the dermal exposure of a child by contact with drift reaching lawn

282 (mg/person/day), \( AR \), application rate (kg a.s./ha), \( \%\text{drift} \), the drift deposition at 8 m of distance

283 (in %), \( \text{TTR}_{\text{turf}} \), turf transferable residue value (0.05), \( TF \), transfer factor (5200 cm²/h), \( \text{DED}_{\text{Child}} \),

284 daily exposure duration (2 h/day).

286 \( \text{DE}_{\text{Child, turf}} = 10^{-4} \times AR \times \%\text{drift} \times \text{TTR}_{\text{turf}} \times SE \times \text{EA}_{\text{Fingers}} \times N_{\text{Events}} \times \text{DED}_{\text{Child}} \)

287 (14)

where \( \text{DE}_{\text{Child, turf}} \) is the dermal exposure of child resulting from hand-mouth activity with turf

289 (mg/person/day), \( AR \), application rate (kg a.s./ha), \( \%\text{drift} \), the drift deposition at 8 m of distance

290 (in %), \( \text{TTR}_{\text{turf}} \), turf transferable residue value (0.05), \( SE \), saliva extraction factor (0.50), \( \text{EA}_{\text{Fingers}} \),

291 exposed area of fingers (20 cm²), \( N_{\text{events}} \), number of hand-to-mouth exposure events per hour (20

292 events/hour), \( \text{DED}_{\text{Child}} \) daily exposure duration (2 h/day).

293 \( \text{DE}_{\text{Child, object}} = 10^{-4} \times AR \times \%\text{drift} \times \text{TTR}_{\text{Object}} \times \text{IgR} \)

294 (15)

295 \( \text{DE}_{\text{Child, object}} \) is the dermal exposure of child resulting from ingestion of turf residues

296 (mg/person/day), \( AR \), application rate (kg a.s./ha), \( \%\text{drift} \), the drift deposition at 8 m of distance

297 (in %), \( \text{TTR}_{\text{Object}} \), object transferable residue value (0.20), \( \text{IgR} \), ingestion rate (25 cm² grass/day).

298 Inhalation exposure and risk indicator of children exposed as bystanders are assessed in the way

299 outlined for bystanders (Equations (10) and (11)). Bodyweight is assumed to be 15 kg.

300

301 2.3.6. Residents

302 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.

\[
313 \quad DE_{\text{Residents}} = AR \times \%_{\text{drift}} \times FA \times EA \times \frac{RD}{365}
\]

(16)

where \( DE_{\text{Residents}} \) is the dermal exposure (mg/person/day), \( AR \), application rate (kg a.s./ha), \( \%_{\text{drift}} \), the drift deposition at 50 m of distance (in %), \( FA \), frequency of applications, \( EA \), exposed area (0.4225 m\(^2\)/person/day), \( RD \), residence days (90 days according to Garreyn et al., 2007).

\[
318 \quad I_{\text{Residents}} = \frac{I_a \times AR \times DED}{ST} \times EF \times YED
\]

(17)

where \( I_{\text{Residents}} \) 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)).
\[ RI_{\text{Residents}} = \frac{(DE_{\text{Residents}} \times Ab_{DE} + I_{\text{Residents}} \times Ab_{I})}{(BW \times AOEL)} \]

where \( RI_{\text{Residents}} \) is the RI for residents, \( DE_{\text{Residents}} \), the dermal exposure (mg/person/day), \( Ab_{DE} \), the dermal absorption factor (0.1 according to Garreyn et al., 2007), \( I_{\text{Residents}} \), 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 3-6 m.

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
will use only data from air-blast sprayer treatments in the risk assessment part of this work. The main operational characteristics of air-blast sprayers are shown in Table 1. According to the interviews, foliar applications from air-blast sprayers cover 7.4 ha per day. An average spraying time of 70 minutes per hectare was used to calculate pesticide inhalation risk. Applications are normally performed in spring and in the end of summer. Some applications for lemon trees are also scheduled in July. Insecticides are the most widely used products for oranges and tangerines and account for 50% of all treatments, followed by foliar fertilizers and plant growth regulators (20%), acaricides (10%) and fungicides (10%). For lemons, insecticide applications represent 60% of treatments and the remaining 40% correspond to acaricide applications.

Table 1.

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

Table 2.

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

In Spain, labels indicate the concentration of plant protection product in the tank, but farmers and
technicians determine spray volume, and consequently, the amount of product applied per unit area. Increasing spray volume while maintaining pesticide concentration leads to significant increases in risk given that the amount of chemical applied per unit area is an important component in predictive models of environmental risk.

3.2. Assessment of risks

3.2.1. Aquatic organisms, earthworms and bees

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

According to Vercruysse and Steurbaut (2002), RI less than one is considered safe while greater than one indicates risk. Aquatic organisms 3 m away from the field may be at risk when applying abamectin, chlorpyrifos, cooper oxychloride, mancozeb, pyriproxyfen or tebufenpyrad because the values of RI were higher than one. Moreover, even with a 20 m buffer zone, aquatic 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 mitigation techniques, such as low-drift nozzles, adjuvants, etc. Precise adjustment of spray volumes would also be helpful. On the other hand, fosetyl-aluminium, gibberellic acid, hexythiazox and 2,4-D would not require the establishment of buffer zones.

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

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

According to all three drift models bees at 3 m have RIs higher than 1 for abamectin and chlorpyrifos. 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).

### 3.2.2 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.

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

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

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References


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