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Aspects of Applied Biology

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Aspects of Applied Biology ***144****, 2020*
International Advances in Pesticide Application

Probabilistic risk assessment for watercourses exposed to spray drift in fruit growing in the Netherlands

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Summary

A countrywide (the Netherlands) risk assessment model has been developed to study the risk of exposure to pesticides for edge-of-field watercourses next to pome fruit orchards. The SPEXUS model was used to compute spray drift deposits onto these watercourses, depending on local and day-of-year weather conditions and growth stage of the fruit tree canopy. A spatio-temporal approach was followed to distinguish between the spatial configuration of the orchard locations and the temporal conditions for multi-year spray applications. Countrywide simulations resulted in 90th percentile concentrations of pesticides (PEC) for various scenarios covering 1 to 15 spray applications and different drift mitigation techniques. A single spatial configuration was selected to evaluate the countrywide risk level for each application scenario. The new risk assessment model, ProSPEXUS, is used in combination with the TOXSWA model for pesticide fate in the ditch. The combined model is to be used for higher-tier risk evaluation for the authorization of plant protection products in fruit growing.

Key words: Spray drift, fruit growing, surface water, risk assessment, probability

Introduction

Deposits of spray drift onto surface waters contribute significantly to the risk of exposure to pesticides for aquatic organisms. This risk is particularly high for surface waters alongside pome fruit orchards, where pesticide sprays are applied in a sideways or an upward direction. The SPEXUS spray drift model has been developed to estimate pesticide deposits onto downwind off-target areas next to fruit orchards (Holterman *et al*., 2017). The model is based on a large number of experimental data from field experiments carried out between 1992 and 2011. Using this spray drift model, the probabilistic exposure assessment model proSPEXUS has been developed to estimate risk of exposure to pesticides for aquatic organisms in edge-of-field watercourses next to pome fruit orchards in the Netherlands. Various spray drift mitigation techniques have been implemented as well.

This paper describes the probabilistic processes concerning the countrywide risk assessment using the proSPEXUS model. Spatial and temporal variables are distinguished. 90% risk levels of predicted environmental concentrations (PEC) of pesticides in surface water can be determined for various spray application schemes including multiple spray applications during a year. In this way, realistic simulations can be carried out to study the exposure and fate of pesticides in surface waters. The exposure assessment model serves higher-tier evaluation for the authorization of plant protection products in fruit growing.

Materials & Methods

In the countrywide spray drift model for the whole of the Netherlands both spatial and temporal variables can be identified. Typically, spatial variables represent the distribution of pome fruit orchards and watercourses across the country, while temporal variables represent the time-dependent quantities like weather conditions. In the next sections spatial and temporal variables are dealt with in more detail.

Basic scenarios were defined to represent the whole set of possible spray applications. For each basic scenario a countrywide spray drift simulation was carried out, giving spray drift deposits on edge-of-field ditches and subsequent pesticide concentrations in the ditches. 90th percentile PEC values were derived.

After establishing the spray drift deposits on the water surface of a ditch, the fate of pesticide in the ditch is followed using the TOXSWA model (Ter Horst *et al.*, 2016). Ideally, the proSPEXUS model and the TOXSWA model must be combined in the countrywide risk assessment. However, this appeared not a feasible option due to the huge amount of computation time involved. Therefore, a single spatial configuration was selected for monitoring. For each basic scenario, the temporal percentile of the selected configuration was determined that corresponded to the countrywide 90th percentile PEC level. In this way, studying the selected spatial configuration could establish a countrywide risk assessment for pesticides in edge-of-field watercourses.

Spatial variables

Fruit orchards are not distributed equally across the country. A regional approach is followed covering 14 districts in the Netherlands, each of which is characterized by its own density of fruit growing areas, regional weather conditions and regional distribution of watercourses (Fig. 1).

Fig. 1. Regional division according to meteorological districts (numbered 2–15); this division is different from the division into provinces; blue dots indicate the location of fruit orchards with edge-of-field water bodies.

Different watercourse types can be identified. Watercourses may have different water levels in winter and in summer, basically due to interventions by the regional Waterboards. As the main topic of interest are spray drift deposits onto surface water, only edge-of-field watercourses are considered, which are located directly adjacent to the orchard (typically a strip of 3 m is between the last tree row and the bank of the watercourse). The watercourse can be situated parallel to the tree rows or at the headland-side of the orchard. Orchards can have different orientations in geographical space; tree rows are often placed in north-south direction to allow for an even illumination by the sun on both sides of the trees.

All these variations lead to about 74,000 different spatial configurations to consider. Situations that do not occur in practice are omitted from this list. Table 1 lists the four major regions with fruit orchards. For each region the sum of lengths of all edge-of-field watercourses next to fruit orchards is determined. The regional weight fraction is defined as the ratio of this length and the similar length for all regions together. There are 14 regions, so on average the regional weight fraction equals 1/14. Table 1 shows that about 43% of all watercourses next to fruit orchards is in the Rivierenland region. Spatial weight fractions (like these) are used to compute the probability of occurrence of different spatial configurations in the model simulations.

Table 1. *Major districts used for regional approach in fruit drift model. District IDs are the numbers from the NHI divisions; informal district names for convenience; only districts with weight fraction above average (=1/14) are listed*

District ID	District name	Weight fraction	Weather station
4	NoordHolland	0.092	Berkhout
7	ZuidHolland	0.127	Cabauw
10	Rivierengebied	0.426	Herwijnen
11	Zeeland	0.160	Wilhelminadorp

Temporal variables

The temporal variables to consider are growth stage and weather conditions. Essentially, temporal variables are functions of the day-of-year and are treated accordingly in the simulation model. Growth stage refers to leaf canopy density which varies during the year and affects the rate of interception of pesticide sprays by the trees. Relevant weather conditions involve wind speed, wind direction and ambient temperature during the time of spray application. Probability distributions have been derived for these weather conditions, derived from data obtained from the website of the Royal Dutch Meteorological Institute (KNMI) for the weather stations representing each region (Table 1). Hourly weather data for the years 1991 through 2010 were used for frequency analyses, for daylight hours only. The probability distributions depend on the dates of application and may vary regionally. Fig. 2a shows the frequency distribution of annual average wind speeds at 10 m above cut grass occurring during daytime. During the year wind speeds vary: in winter average wind speed is higher than in summer. Fig. 2b shows the daily mean wind speed as a function of week number. Assuming the frequency distribution for each day of the year has the same shape as the yearly average of the left-hand graph, the mean wind speed of the right-hand graph can be used to scale the left-hand graph to obtain daily appropriate frequency distribution for each day of year (DOY). The SPEXUS spray drift model requires the wind speed at 4 m height in the orchard area. This wind speed can be derived from that at 10 m height, assuming a logarithmic wind speed profile and correcting for average tree height. For an average tree height of 2.25 m the wind speed at 4 m is about 0.66 times the wind speed at 10 m height. Note that 'good agricultural practice' (GAP) requires that spray application must not be carried out when wind speed is above 5 m s^{-1} at agricultural level. This implies that at 10 m height the average wind speed must not exceed 7.6 m s^{-1}

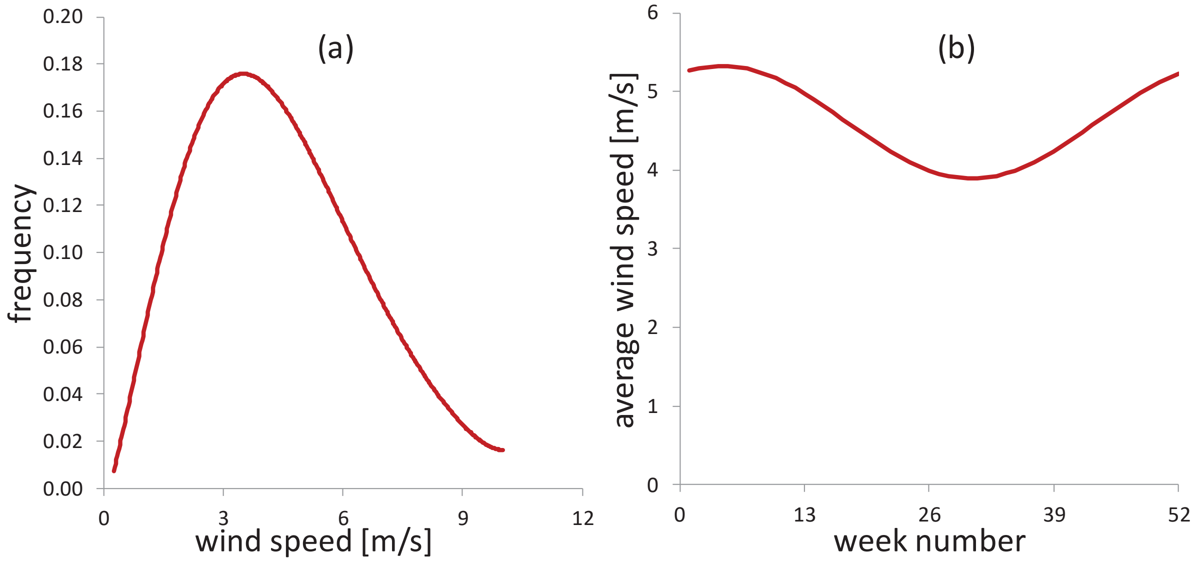

Fig. 2. Wind speed statistics for weather station Herwijnen (district 10; 1991–2010). Left: frequency distribution of hourly averaged wind speeds during daylight hours. Right: mean wind speeds (daylight hours) as a function of week number.

Similarly, an annual frequency distribution for wind direction has been derived. Dependence on DOY appeared to be relatively low, so the annual distribution was used for each DOY (Fig. 3a).

Finally, weekly averaged temperatures at daylight hours were examined. Fig. 3b shows the daily averaged temperature throughout the year. For each DOY, hourly temperatures were almost normally distributed around their mean, with standard deviation of about 4°C.

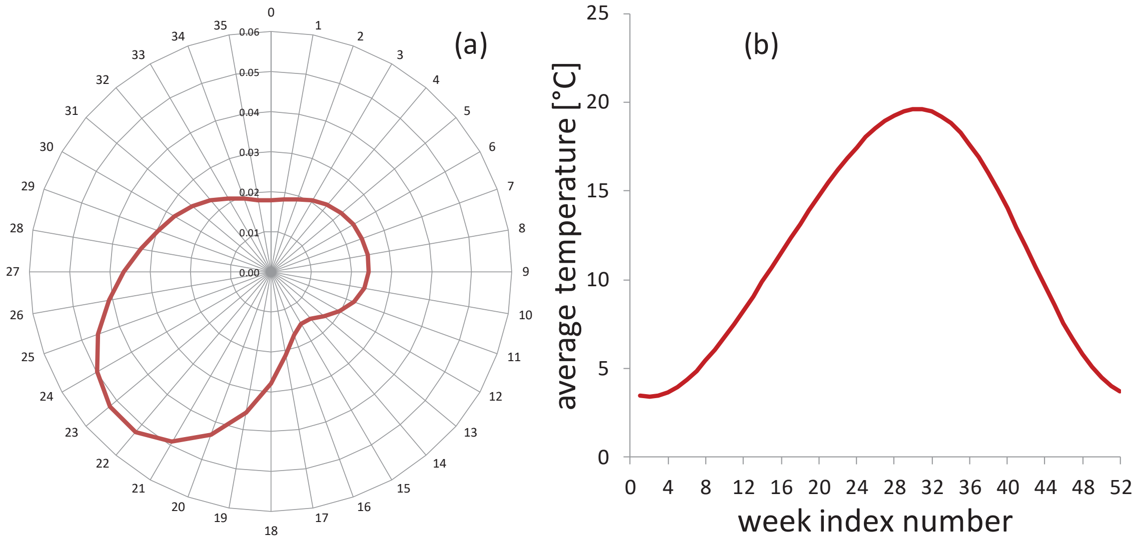

Fig. 3. Statistics for temperature and wind direction for weather station Herwijnen (district 10; 1991–2010). Left: frequency distribution of hourly averaged wind directions during daylight hours. Right: hourly averaged temperatures during day-time throughout the year.

Spray application schemes

The number of spray applications in fruit orchards may vary between once and about 15 times per year during the growing season. This depends on the chemical used and the pressure of the pest or disease to be controlled. Many pesticides are applied only once or twice a year, from spring to late summer. For multiple pesticide applications, a typical minimal interval is one week. The acute risk that aquatic organisms are exposed to is governed by the highest pesticide concentration (PEC) in the watercourse. For slowly dissipating pesticides, multiple spray applications may lead to high cumulated PECs. For fast dissipating pesticides, the application giving the highest PEC dominates the risk level. Often, dissipation is fast enough to consider the latter case as the more common one. Therefore, in this study the cumulation of PECs in multiple spray applications is not investigated further.

To limit the vast number of possibilities to a set of representative scenarios, five basic scenarios were defined. These basic scenarios are identified by 'early' applications (spring, little leaf stage) or 'late' applications (late summer, trees in full leaf) and one, three or 15 weekly applications, while complete pesticide dissipation in the exposed ditch is assumed within a week.

Results

Countrywide scenarios

Each of the basic scenarios was studied on a countrywide scale, for all possible (~74,000) spatial combinations of regions, watercourses, water levels, orchard orientations. Spatial combinations that do not exist in practice are not counted in this number. Each spatial combination has its own (realistic) probability and simulation results are weighted accordingly (the regional weight fraction of Table 1 is an example). Simulations were carried out for 100 years with random weather conditions, selected from the appropriate frequency distributions for wind speed, wind direction and ambient temperature. Weather conditions and crop growth stage corresponded with the dates of spray application. In this way a realistic multi-year simulation study was obtained consisting of more than 7 million pesticide concentrations in edge-of-field watercourses for each of the basic scenarios. From these distributions the 90th percentile PEC values were determined.

As an example, Fig. 4 shows the cumulative probability distributions of PEC values for three spray application scenarios: a single application at the beginning of May, three applications in May and 15 applications throughout the growing season. The dotted line indicates the 90th percentile level, showing that each scenario has its own 90th percentile PEC value. In a similar way, for each basic scenario 90th percentile PEC values were obtained from countrywide probability distributions.

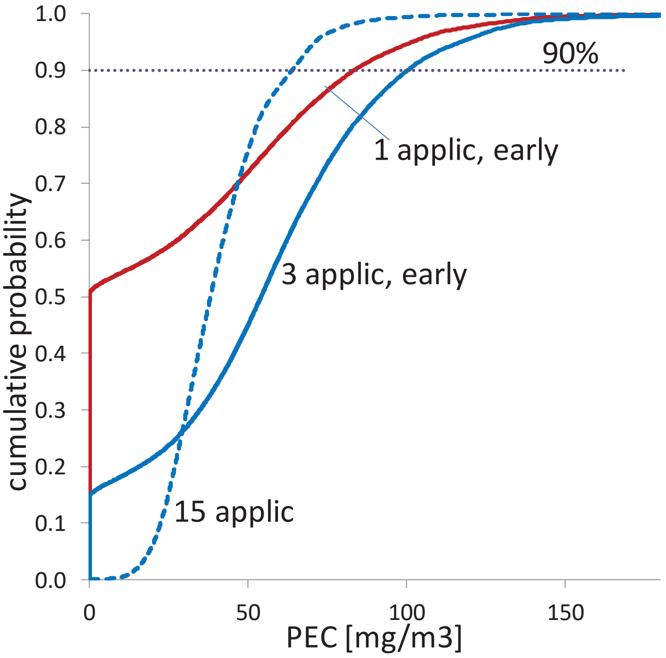

Fig. 4. Cumulative probability distribution of PEC values for three spray application scenarios.

Selecting a representative spatial configuration

A single spatial configuration was selected to represent the countrywide situation. Criteria for this selection involved among other factors a region with lot of fruit growing and a watercourse type and orchard orientation frequently occurring. Clearly the countrywide 90th percentile PEC value should be contained by the range of PEC values possible in the selected watercourse. It turned out that it was possible to select a single spatial configuration to represent all basic scenarios.

As an example, for a single early spray application (1 May), the countrywide 90th percentile PEC level is about 83 mg m^{-3} (Fig. 5). For the selected spatial configuration, this PEC value is found at temporal percentile 58%. In other words, the 58th percentile of the PEC distribution for the selected ditch equals the countrywide risk assessment level for this scenario. Similarly, for each basic scenario a representative temporal percentile was determined to represent the corresponding 90th countrywide level.

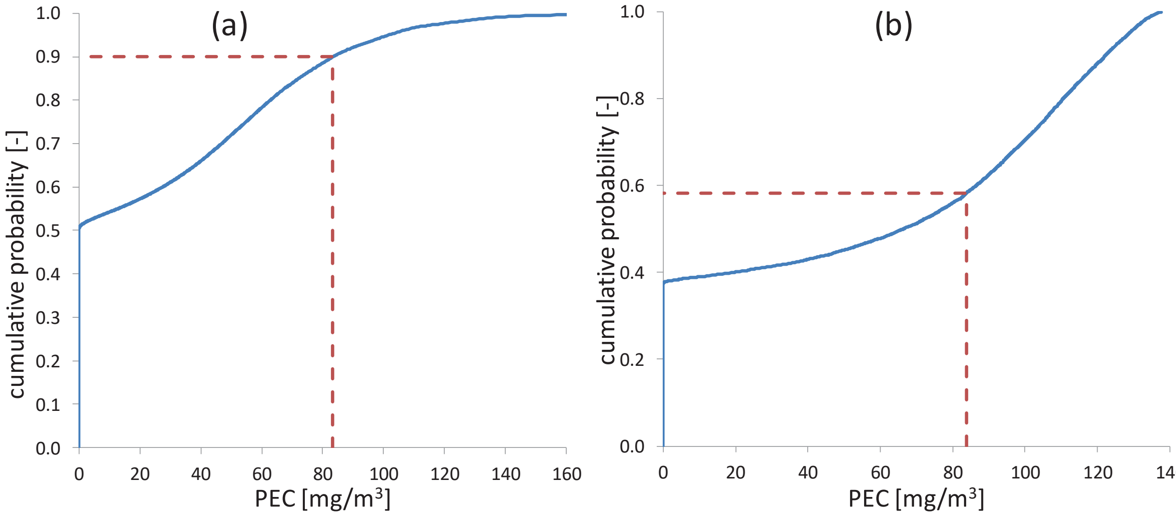

Fig. 5. Left: countrywide cumulative probability distribution of PECs for a conventional spray application early May. Dashed lines indicate the 90th percentile PEC value. Right: cumulative probability density curve for the corresponding selected spatial configuration; dashed lines: the 90% PEC value from (a) leads to a temporal percentile of about 58% for the selected ditch.

The five basic scenarios, combined with different spray application techniques and crop-free buffer zones, resulted in 350 distinctive situations each with its own countrywide 90th percentile PEC value and a corresponding temporal percentile for the selected spatial configuration.

Dealing with non-basic scenarios

Although the set of 350 predetermined situations seems large, it still not covers all spray application scenarios that are possible in practice. Therefore, several actions were required to cope with non-basic scenarios. In some cases, one of the predetermined scenarios was selected that best resembled the actual scenario and the temporal percentile of that predetermined scenario was used. In other cases an interpolation between two predetermined situations seemed more appropriate. For instance, the basic scenarios only involve one, three and 15 spray applications. For say five applications, the temporal percentiles for three and 15 applications were interpolated, giving a reasonable estimate of the required temporal percentile.

Discussion

A countrywide risk assessment model, proSPEXUS, has been developed for evaluating deposits of spray drift onto edge-of-field watercourses next to pome fruit orchards in the Netherlands. Several realistic spray application scenarios have been carried out, resulting in corresponding 90th percentile risk levels of PECs in surface waters. The model takes into account realistic weather conditions on a regional scale, varying growth stages during the growing season and regional differences in topography. A wide range of spray application scenarios can be simulated, including the use of drift mitigation techniques and crop-free buffer zones. All of these features result in a versatile exposure assessment model with a high level of realism.

The spray drift deposits onto the water surface can be used as input for models describing the fate of pesticides in the watercourses. Currently, the present model is combined with the TOXSWA fate model. In this way, a realistic simulation study on the exposure to and fate of pesticides in surface waters can be performed to quantify exposure risk levels for aquatic organisms. This serves higher-tier assessment studies for the authorization of plant protection products.

Acknowledgements

The authors thank the Dutch Ministry of Economic Affairs (project number BO-20-002-003) for funding this research.

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