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Modelling the exposure of water bodies to spray drift for fruit growing in the Netherlands

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Summary

An innovative spray drift model for fruit orchards in the Netherlands has been developed recently. The model is implemented in an assessment model for the exposure of watercourses to deposits of pesticide spray drift for all water bodies next to fruit orchards in the Netherlands. The exposure assessment model accounts for a large number of spatially and temporally varying conditions. These include spatial distributions of orchards and their orientation, edge-of-field watercourses of various types, spatio-temporal frequency distributions of weather conditions (wind speed and direction, ambient temperature). Another important factor is the growth stage of the trees at the time of pesticide application. Drift reducing application techniques and multiple spray applications during the growing season are accounted for. All of these features result in an assessment model that expresses a high level of realism. In an extensive simulation study the predicted environmental concentrations (PECs) in the watercourses were computed for all possible spatial settings. The results of these simulations are used in a simulation study on the fate of pesticides in surface waters to quantify exposure risk levels for aquatic organisms. This serves as a higher-tier assessment studies for the authorization of plant protection products.

Key words: Spray drift, modelling, pesticides, fruit orchards, surface water, risk assessment

Introduction

In the Netherlands, the potential contamination of surface waters after applying chemical pesticides to crops still is of major concern. In fruit orchards, sprays are applied in an upward or sideways direction with air support, which may give rise to considerable deposits of spray drift onto water bodies adjacent to the orchards. An innovative spray drift model for fruit crops has been developed recently (Holterman *et al*., 2016). The current study describes the implementation of this drift model into an assessment model for the exposure of watercourses to pesticides for all water bodies next to fruit orchards (typically pome fruit trees) in the Netherlands.

While the underlying drift model requires growth stage and weather conditions as input, the exposure assessment model also accounts for differences in weather conditions and frequency distributions of various water body types. These parameters may vary spatially (depending on the regions where the orchards are located) and temporally (depending on the dates of the spraying events). A special feature of the assessment model is the possibility to allow repeated applications during the growing season. All of these features result in an assessment model that expresses a high level of realism.

In an extensive simulation study the predicted environmental concentrations (PECs) were computed for all possible spatial settings (defined by the characteristics of orchards and adjacent water bodies). Several scenarios were simulated, covering 1–3 spray applications in spring and summer and an application scheme for the whole growing season. One spatial setting corresponding to a 90% exposure risk for each scenario could be distinguished. This spatial setting was selected as a reference case for a higher-tier model that describes the fate of pesticides in the watercourses in the authorization of plant protection products.

Materials & Methods

Risk assessment model for exposure of aquatic organisms to pesticides

The recently developed spray drift model for fruit orchards (Holterman *et al.*, 2016) is embedded in a risk assessment model for the exposure of edge-of-field watercourses to pesticides next to fruit orchards on a countrywide scale. Since fruit orchards appeared to be more abundant in some parts of the Netherlands than in other parts, a regional approach proved useful. The whole of the country was divided into 14 regions which were considered as homogeneous units regarding meteorological conditions, land use and topography of the watercourses. Water body types that may fall dry during summer were excluded from the list, following the EFSA guidance on risk assessment for aquatic organisms (EFSA, 2013). Other parameters of importance are the orientation of the orchard (often tree rows are planted along the North-South direction), regional occurrence of fruit orchards and water body types and regional weather conditions. For these variables frequency distributions are determined (in space and/or time).

The assessment model distinguishes spatial and temporal variables. The simulations comprise all possible combinations of the spatial quantities, weighted by their probability of occurrence. In contrast, the temporal quantities (like weather conditions) are selected randomly from their frequency distributions. This requires a large enough number of simulation years to obtain statistically precise results

A risk assessment scenario consists of the computation of deposits of spray drift for all combinations of water body types and regional environmental conditions. The simulation model returns a list of spray deposits onto surface waters for all spatial combinations and all simulated years. A scenario is defined by the number and dates of pesticide applications and the spraying technique used. From the spray deposits the predicted environmental concentration (PEC) in the watercourse is determined, assuming instant and homogeneous mixing of the pesticide in the water.

The flow-chart of the risk assessment model is shown in Fig. 1. The left part shows the loops of spatial quantities. The nested loops comprise almost 74000 different spatial combinations. The dashed rectangle represents the stochastic loops of temporal quantities including multiple (m) spray applications per season and the n-year loop. This is shown in detail in the flow-chart on the right-hand side. In the following sections the various frequency distributions used in the risk assessment model are described. The actual spray drift model is represented by the block heading ‘compute drift’. The next sections discuss some of the spatial and temporal variables in more detail.

Frequency distribution of water bodies

In the Netherlands, water bodies with water surface width <6 m have been classified into 66 standard profiles according to soil type, water body geometry and flow rate (Massop *et al.*, 2006). Often only a few standard profiles are present regionally. Besides, some profiles are likely to dry up in summer and therefore are excluding from risk assessment for exposure of water organisms to pesticides. Consequently, the regional frequency distribution of water bodies consists of a limited number of profiles (4–19 water body types per region).

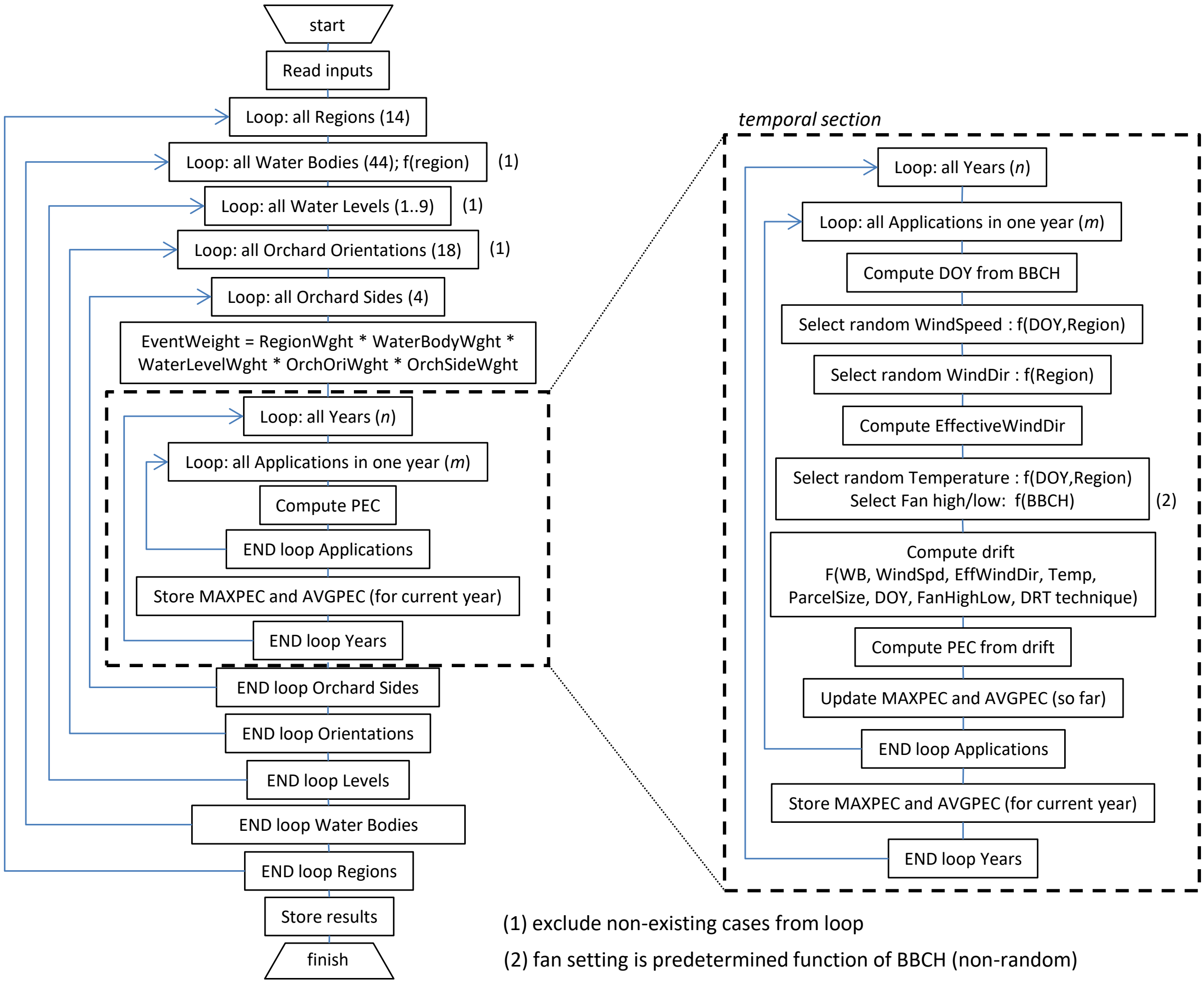

Fig. 1. Flow-chart of the risk assessment model (*left*). The dashed block in the centre is the temporal section and is expanded on the right-hand side.

Frequency analysis of meteorological data

Meteorological data were obtained from KNMI[1] weather stations representative for the various regions. Hourly averaged values of wind speed, wind direction and air temperature were gathered for daylight hours only, since spray applications only take place during the day. Data during 20 recent years (1991–2010) were used. In the following sections examples are given of these data, for the weather station in Herwijnen (representative for the central rivers area, 'Rivierengebied', the most important region for fruit growing). Each weather station has its own set of distribution curves and averages to be used in the risk assessment tool.

Frequency distribution of wind speeds

Fig. 2, left, shows the 20-year averaged frequency distribution of wind speeds at 10 m height during daylight hours for the weather station in Herwijnen. The median wind speed is 4.0 m s^{-1}, though occasionally very high wind speeds have been measured. Ideally, sprays are applied only when the average wind speed is below 5 m s^{-1} (at 2 m height above cut grass). The frequency values for wind speeds up to 10 m s^{-1}were fitted using a 6^{th} grade polynomial (the black curve in Fig. 2, left). In winter, wind speeds are on average higher than in summer. Fig. 2, right, shows the weekly averaged wind speeds during the year, roughly following a sinusoidal curve. The

[1] KNMI = Royal Dutch Meteorological Institute

year-averaged frequency distribution was scaled in such a way that for each day-of-year (DOY) the appropriate distribution was obtained (i.e. having a mean wind speed equal to that given by the sinusoidal curve). In this way, the DOY-adjusted polynomial frequency distribution could be used for stochastic selection of wind speeds in the risk assessment tool. Such distributions were prepared for each region.

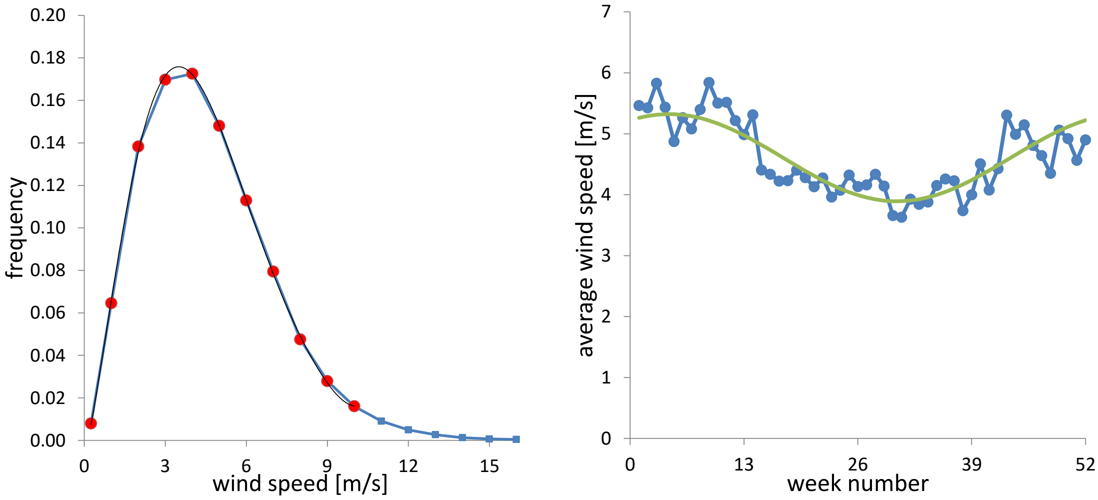

Fig. 2. *Left*: normalized frequency distribution of hourly averaged wind speeds at 10 m height through the year (at daylight only); red dots: measurements selected for curve fitting a 6th grade polynomial (black line); blue squares: measurements not used in curve-fitting. *Right*: weekly averaged wind speeds during the year; blue dots: measurements; green line: Fourier fit. (Meteorological station Herwijnen; Rivierengebied; 1991–2010).

Frequency distribution of wind directions

In the Netherlands, wind often blows from the SW direction. This is clearly supported by Fig. 3, showing the angular frequency distribution of wind direction at the Herwijnen weather station. 'Effective' wind direction is defined as the wind direction relative to a cross wind and therefore it is related to the orientation of the fruit orchard concerned. Fruit orchards are not oriented randomly; often the rows of trees are oriented along the NS direction, such that both sides of the trees receive the same amount of daylight. Sometimes orientation depends on the local situation as well (e.g. parallel to neighbouring roads or water bodies). Frequency distributions of wind direction and orchard orientation are combined to give the frequency distribution of effective wind direction, to be used in the risk assessment tool.

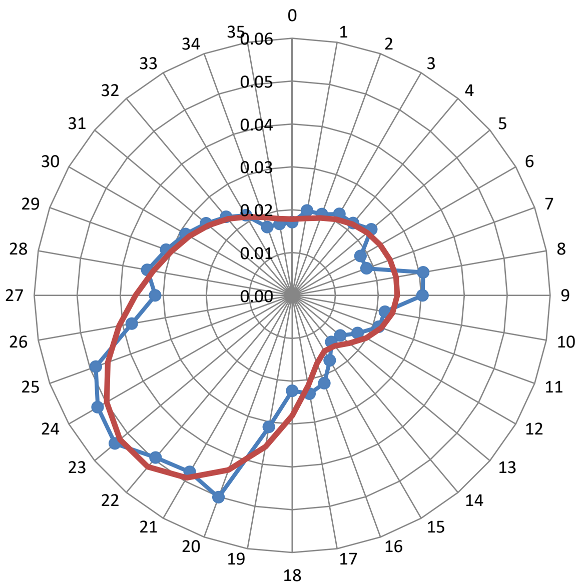

Fig. 3. Angular frequency distribution of hourly averaged wind direction (at daylight hours only); blue dots: measurements; red line Fourier fit. (Meteorological station Herwijnen; Rivierengebied; 1991–2010).

Simulations for scenarios for risk assessment

Fig. 4 shows the week numbers of application for various pesticides in apple orchards. Most pesticides are applied only once or twice in spring or summer. There is one clear exception: captan is applied often from spring until autumn. From this application scheme eight scenarios are defined to represent applications in practice (Table 1), depending on number and dates of the applications and the dissipation rate of pesticide in the watercourse. For 'early' applications the canopy density of the trees is still low. For 'late' applications the canopy is in full leaf. Multiple applications are assumed to take place at 7-day intervals.

For multiple spray applications within the growing season, two extreme cases can be distinguished. Firstly, pesticide concentration in a water body may vanish between subsequent spray applications. Such dissipation may be due to degradation, sedimentation and/or uptake by the soil underneath, or transport by water flow. In this case, the risk for aquatic organisms in a watercourse is caused by the application giving the highest PEC (MAXPEC). Secondly, pesticide concentration may remain constant between spray applications, when there is no dissipation whatsoever. Subsequent applications lead to increased pesticide concentrations, since these add up during the season. In that case, the risk for aquatic organisms in the watercourse is caused by the sum of all PECs of the individual applications. For ease of comparison, it is convenient to use the average concentration instead (AVGPEC), defined by the ratio of the summed PECs and the number of applications.

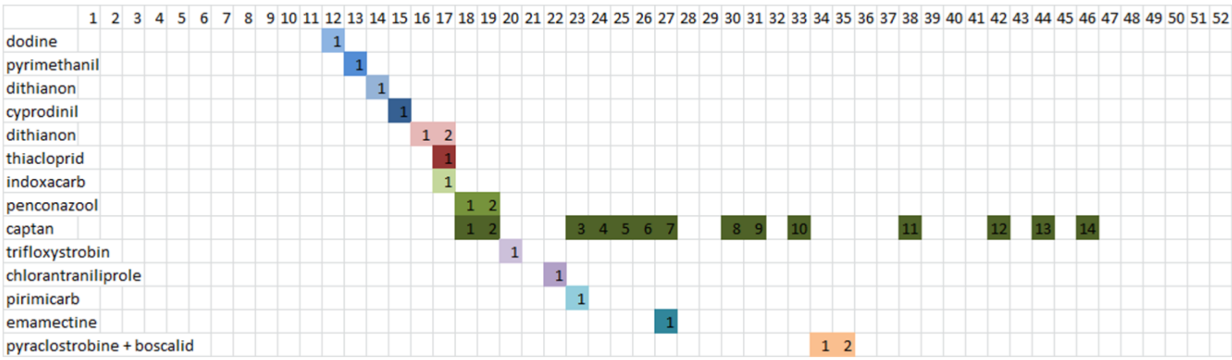

Fig. 4. Typical pesticide application scheme for apple orchards in the Netherlands, showing week numbers of applications for various pesticides.

Table 1. *Basic scenarios for risk assessment simulations*

scenario index	1	2	3	4	5	6	7	8
# applications	1		3		3		15	
application date	early	late	early		late		n/a	
BBCH	70	80	70–73		80–85		75–87	
dates	May 4	Aug 29	May 4–18		Aug 29–Sep 12		June 17–Sep 23	
pesticide dissipation	n/a		fast	slow	fast	slow	fast	slow

Results

Some examples of using the risk assessment model are presented here. A countrywide simulation over 100 years results in >7 million PEC values. After sorting these values, a cumulative probability density function (cpdf) can be constructed. The left graph of Fig. 5 shows the cpdf curves for MAXPEC after one and three pesticide applications in spring and 15 applications from spring till autumn (scenarios 1, 3 and 7 from Table 1). Similarly, the graph on the right-hand side shows the cpdf curves for AVGPEC (scenarios 1, 4 and 8). For one application, half of the watercourses is on the upwind side, regardless of wind direction. Therefore the corresponding cpdf intercepts the y axis at about 0.5. For multiple applications, the probability that a watercourse is always on the upwind side is decreasing with increasing number of applications. The 90th percentile PEC values are a common measure of the risk level. These values can be derived from the curves and are given in Table 2.

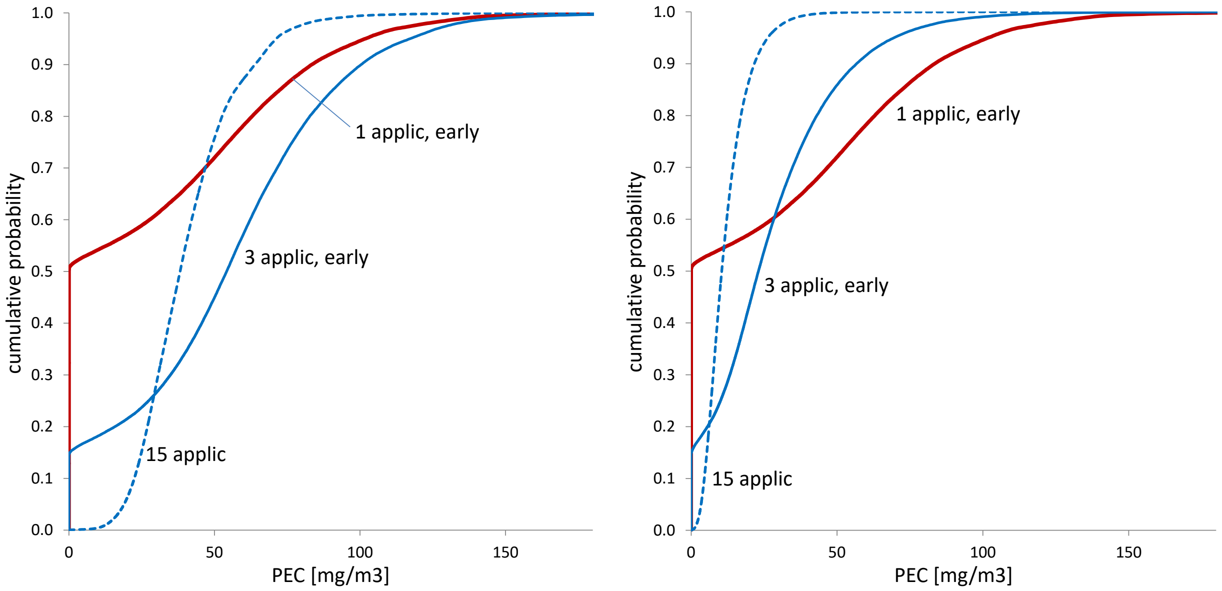

Fig. 5. Examples of cumulative probability curves for PECs in edge-of-field watercourses for spray applications in fruit orchards in the Netherlands. Number of applications during the season: 1, 3 and 15; number of simulated years: 100. *Left*: curves for MAXPEC. *Right*: curves for AVGPEC.

Table 2. *Simulations from Fig. 5; 90th percentile PECs*

scenario index	1	3	7	4	8
PEC type	MAX=AVG	MAX	MAX	AVG	AVG
90% PEC [mg m^{-3}]	83	100	64	57	22

Discussion

The risk assessment model can compute pesticide concentrations in edge-of-field water bodies for all regions in the Netherlands where fruit orchards are present. Different realistic scenarios can be simulated for which risk levels can be determined conveniently using cpdf curves. Eight basic scenarios are selected, but the model is not limited to these. The results will be used for further investigation of the fate of pesticides in water courses, in higher-tier assessment studies for the authorization of plant protection products.

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