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Possibilities to reduce drift by 75 percent in biocidal applications of insecticides with cannon sprayers

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Abstract

Background Insecticides are applied on a large scale in the environment to control the oak processionary moth (*Thaumetopoea processionea*) for the protection of human health. Drift of the insecticides to non-target areas is a risk for the surrounding biodiversity. Since the habitats of the caterpillars are usually restricted to the treetops, the sprayers used to apply biocidal products must be able to transport the droplets over longer distances. Therefore, cannon sprayers are often used. In this study, spray drift in an oak avenue from a cannon sprayer with hydraulic atomisation was measured with two different nozzles. The aim of this study is to compare spray drift when using a cannon sprayer with different drift-reducing nozzles with cannon sprayers with pneumatic atomisation to find options to reduce drift to non-target areas.

Results The results show that compared to the basic drift values for biocidal products using a cannon sprayer with pneumatic atomisation, a cannon sprayer with ID-120-05 POM nozzles achieves a drift reduction of 75% and a classification in this reduction class. No drift reduction could be determined with a cannon sprayer with AirMix 110-05 nozzles.

Conclusions Better knowledge of drift of biocidal products is of utmost urgency in order to be able to compare and classify the currently used technologies. When using a cannon sprayer, this study shows that specific drift values are recommended based on the type of atomisation, as droplet size is an important factor in reducing drift. By choosing the technology with the highest drift reduction, the drift of biocidal products into the environment can be minimised by 75%, thus ensuring a much better protection of the environment.

Keywords Biocides, Cannon sprayer, Hydraulic atomizer, Basic drift value, Drift reduction class, Environmental exposure, Drift risk

Background

Spray application of insecticides is a common method to control *Thaumetopoea processionea*, the oak processionary moth (OPM) [1]. As the caterpillars often restrict their habitat to the treetops [2], the sprayers have to transport the droplets over long distances, which greatly increases the risk of spray drift to non-target areas.

In order to know which laws to follow in control measures against OPM, it is necessary to know whether the focus is on protecting trees or people and animals. In cases where the focus is on protecting trees, insecticidal plant protection products are used [3] and all legal requirements for plant protection must be met. If, on the other hand, the protection of human and animal health against the poisonous hairs of OPM is the primary concern, insecticidal biocidal products are used [4]. The fact that these two product categories are regulated in

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different European regulations leads to different requirements for the equipment used.

Directive 2009/128/EC on the sustainable use of pesticides requires that the most efficient application techniques, such as the use of low-drift technology, should be used, especially for vertical crops [3]. In order to find the most efficient application technology, an up-to-date compilation of many plant protection devices and parts is included in the "Descriptive List", which is published in the Federal Gazette [5]. At the request of the manufacturers, the Julius Kühn Institute (JKI, Federal Research Institute for Cultivated Plants) carries out technical tests on several test facilities. If the test is completed successfully, a device test report is published and the device is included in the list. At the request of the manufacturer, the spray drift reduction of a successfully approved device can be measured. The spray drift reduction is measured methodically according to the JKI guideline 7-1.5 [6]. The basic drift values are the basis of this guideline. In the 1990s, basic drift values were developed as an exponential function of the plants treated and the distance from the treated area [7, 8]. To this day, the measured spray drift of the test equipment is compared with these basic drift values and spray drift reduction classes are derived for the approval report [9].

However, the list of basic drift values only includes areas of application for the use of plant protection products. Application areas for the use of biocidal products such as forest edges, solitary trees, avenues and urban application areas such as buildings or their surroundings are not included and have therefore not been investigated so far. This is because Directive 2009/128/EC only applies to pesticides, which are plant protection products, but not to biocidal products [3]. A separate directive for the sustainable use of biocides has not yet been developed, and there are currently no further regulations for the equipment used to apply biocides. This leads to inconsistent conditions: for example, it is possible to use a cannon sprayer for biocidal products, although the use of this equipment is not recommended for plant protection products in comparable environments due to the high risk of spray drift. The initial field tests to determine basic drift values for biocidal products were carried out by the JKI on behalf of the Federal Environment Agency in Germany. In these studies, Langkamp-Wedde et al. [10] carried out large-scale spray drift measurements to determine basic drift values for OPM control at the forest edge, on solitary trees and on avenues. A helicopter, an unmanned aerial vehicle and a cannon sprayer with pneumatic atomisation were used. On the basis of these investigations, basic drift values were recommended, which were recognised by the member states of the European Commission [11].

However, this research on the spray drift potential of cannon sprayers so far is limited to cannon sprayers with pneumatic atomisation. To be able to decide which type of equipment reduces spray drift to non-target areas the most, research on cannon sprayers with hydraulic atomisation is needed as well. In this study, spray drift is measured for the first time using a hydraulic cannon sprayer with different nozzles on an avenue of mature oak trees to estimate the potential for spray drift, compare these values with the basic drift values of pneumatic cannon sprayers and to develop measures to mitigate spray drift for this specific application area. This should help to protect non-target areas in the environment from biocides and contribute to the protection of biodiversity.

Material and methods

Two systems are available on the market for controlling OPM on mature oaks with a cannon sprayer: cannon sprayers with pneumatic atomiser and cannon sprayers with hydraulic atomiser. The spray drift of cannon sprayers with pneumatic atomiser on an avenue was measured by Langkamp-Wedde et al. [10] and basic drift values were also derived [11]. In this study, the spray drift of cannon sprayers with hydraulic atomiser and two different nozzles is measured in a realistic environment and compared with the basic drift values of a cannon sprayer with pneumatic atomisation. Possible spray drift reduction classes are also derived.

Cannon sprayer with hydraulic atomiser

The cannon sprayer used was the Dragone AZ2 (Dragone, Castagnole Lanze, Italy) with a hydraulic atomisation. The tank had a capacity of 1000 L. The pump capacity of the sprayer was 88 L min^{-1} at a power take-off speed of 540 rpm. Eight nozzles could be mounted outside the air stream to spray the liquid directly into the air stream (Fig. 1). The working speed was about 1.6 km h^{-1} and the nozzle pressure was 8.0 bar. The equipment settings correspond to the settings in practical use as made by the contractor.

Nozzle types and classification

The nozzles AirMix 110-05 (agrotop GmbH, Obertraubling, Germany) and ID-120-05 POM (Lechler GmbH, Metzingen, Deutschland) were used to investigate their influence on spray drift behaviour. Both nozzle types have a flow rate of 3.22 L min^{-1} at 8 bar [12], resulting in a total flow rate of 25.76 L min^{-1} for the eight nozzles.

The AirMix 110-05 is a low-pressure injector flat fan nozzle with coarse to very coarse droplet size [13]. The ID-120-05 POM is an air injector flat fan nozzle with a very coarse droplet size [14]. Table 1 shows the main

Fig. 1 Tractor-mounted cannon sprayer Dragone AZ2 (left) with hydraulic atomiser (right)

Table 1 Main parameters and the droplet size spectrum of the nozzles used in the trials

Name	 **AirMix 11005**	 **ID-120-05 POM**
Manufacturers	Agrotop	Lechler
Nozzle size [–]	05	05
Spraying angle [°]	110	120
Flow rate [l min^{-1}]	3.22	3.22
$D_{v0.1}$[a] [μm]	115.3	126.9
$D_{v0.5}$[a] [μm]	236.6	310.1
$D_{v0.9}$[a] [μm]	454.8	643.0
V_{100}[b] [%]	7.81	6.43
Drop size classification	Medium	Coarse

[a] $D_{v0.1}$: 10% of spray liquid volume fraction is made up of droplets smaller than this value; $D_{v0.5}$: volume median diameter; $D_{v0.9}$: 90% of spray liquid volume is made up of droplets smaller than this value

[b] V_{100}: spray liquid fraction generated with small droplets (< 100 μm)

parameters and the droplet size spectrum according to the ISO 25358:2018 [15] at 8 bar, the pressure used in the trials (internal JKI results). In conclusion, the AirMix 110-05 nozzle has the highest proportion of fine droplets and has a higher spray drift behaviour than the ID-120-05 POM nozzle.

In the following, the cannon sprayer with pneumatic atomisation is referred to as the pneumatic cannon sprayer, while the combinations of the hydraulic cannon sprayer and the two different nozzles are referred to as the cannon sprayer AirMix 110-05 and cannon sprayer ID-120-05 POM.

Procedure for measuring spray drift on an avenue

The JKI guideline 7.1-5 “Measuring of direct drift when applying plant protection products outdoors” [6] was used as the basis for measuring the spray drift of the cannon sprayer on an avenue. The JKI guideline is identical to the ISO 22866:2005 standard [16] in many areas, such as the orientation of the treated area and the measuring area. With regard to weather conditions, the JKI guide is even stricter. The air temperature must not exceed 25 °C during the entire trial. The average wind speed must be between 2 and 5 m s^{-1}. Therefore, the JKI guideline is more suitable for risk assessment.

The treated area was a single-row avenue of mature oaks at the Langelsheim location (51°57′09.7″N 10°16′14.2″E) in Lower Saxony, Germany. The avenue was 125 m long, about 20 m high and 23 m wide, corresponding to a sprayed area of 2.875 m^2.

The trials were conducted in July 2020. The average application time was 3:45 min. The working pressure was set at 8.0 bar and the avenue was treated once. This resulted in an average liquid volume of 403 l ha^{-1}. The spray tube was tilted to 75° so that the tractor track was 15 m beside the avenue and the cannon sprayer sprayed the liquid into the crown on the windward side (Fig. 2). The service providers explained that this method corresponds to the settings in real applications as carried out by the contractor. Treating an avenue in a practical manner was the aim of these trials, with the background of testing the state of the art. In addition, the application was repeated four times for each nozzle. The cannon sprayer was not equipped with a gap detection system.

The spray liquid was water with pyranine (CAS number 6358-69-6) as fluorescent tracer dye in a concentration of 2 g L^{-1}. Pyranine is a green-yellow, powdery sodium salt

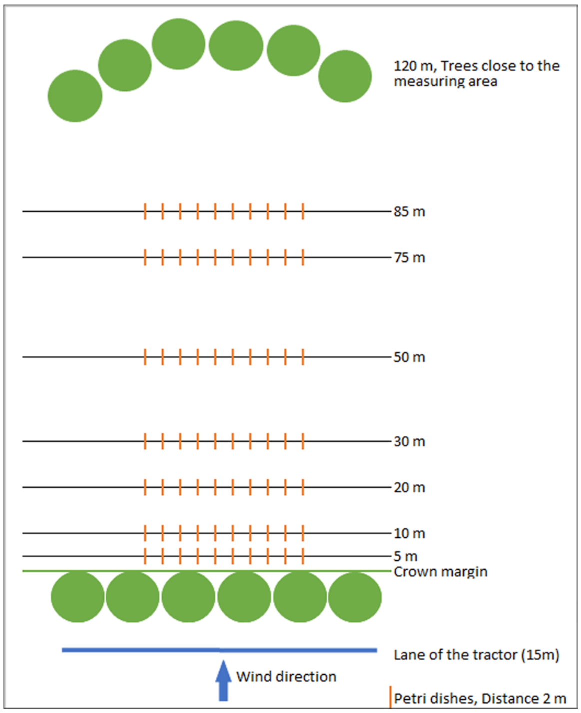

Fig. 2 Schematic figure of the trial area during application, not in scale

(trade name: Pyranine 120%, colour index: Solvent Green 7) and has a recovery rate of almost 100% [17]. Tank samples were taken during the trials to check the application rate and to determine whether the tracer concentration was stable throughout the application.

The measuring area was aligned according to the mean wind direction. Petri dishes as collectors were placed on wooden slats on the downwind side of the avenue. The Petri dishes had a diameter of 145 mm. According to the JKI guideline 7-1.5, this is sufficient to record a representative section of the entire spray drift. The measuring distances to the crown edge were 5, 10, 20, 30, 50, 75 and 85 m. At each measurement distance, 10 collectors were placed 2 m apart. Five minutes after spraying, the collectors were closed and immediately protected from light. The analysis of the tracer took place in the laboratory with a fluorometer (RF-6000, Shimadzu Duisburg, Germany). In addition, collectors were set up outside the measuring area to determine the blank value. Herbst and Wygoda [17] found that the use of pyranine for measurements with plastic collectors proves its suitability without major restrictions. If the tracer is used outdoors with filter paper or plant leaves, problems with decay by ultraviolet light may occur.

During all applications, the weather data (wind direction, wind speed, air temperature and relative humidity) were constantly recorded at a frequency of 1 Hz. Valid trials according to the above-mentioned JKI guideline 7-1.5 are trials with an air temperature not exceeding 25 °C, a relative humidity above 30%, wind speed between 2 and 5 m s^{-1} and a wind direction at right angle to the tractor's track (±30°).

Laboratory analysis

The collectors used were stored in a dark, cool room and analysed within 4 days of the trials. For the analysis, the tracer (pyranine) was extracted from the collectors with distilled water. For this purpose, 40 mL of distilled water was filled into the collectors and shaken for 10 min on a shaking table at 65 rpm. The frequency and amplitude were chosen so that the inner walls of the collectors were completely washed around. For the analysis of pyranine in the wash water of the collectors, the fluorometer RF-6000 (Shimadzu Duisburg, Germany) with an excitation wavelength of 405 nm and an emission wavelength of 515 nm was used.

Calculation of spray drift

Spray drift is expressed as ground sediment as a percentage of the application rate. A calibration line is used to calculate the spray drift (Eq. 1):

$$\beta_{dep} = \frac{(\rho_{smpl} - INT)}{\Delta_{calib}} * \frac{V_{dist}}{A_{colle}}, \tag{1}$$

where β_{dep} is the spray drift deposit [μg cm^{-2}]; ρ_{smpl} is the fluorometer reading of the sample [−]; INT is the intercept of the calibration curve [−]; Δ_{calib} is the slope of the calibration curve [L μg^{-1}]; V_{dist} is the volume of distilled water [L] and A_{colle} is the area of the collector to collect the spray drift [cm^2].

The percentage compared to the application rate was calculated using Eq. 2:

$$\beta_{dep\%} = \frac{\beta_{dep}}{TR} * 100\%, \tag{2}$$

where $\beta_{dep\%}$ is the spray drift [%] and TR is the tracer rate [μg cm^{-2}].

Statistical analysis

The measured spray drift values are displayed in a boxplot using R version 4.1.1 with the package "lattice". The boxplot shows the median (50th percentile), 25th percentile, 75th percentile and extreme values of all measured values within a distance and a combination of sprayer and nozzle. The median.test was used to determine the differences between the nozzles within a distance from the treated area. The median.test is a non-parametric test and does not require a normal distribution and homogeneity of the data. In addition, different letters were used to identify significant differences between the sprayer and nozzle combination within a distance from the treated area.

Basic drift values are based on the 90th percentile of the measured drift values and are used for the risk assessment of pesticides [8, 18]. The 90th percentile of the spray drift values was compared with the basic drift values to check whether the basic drift values can be achieved with the sprayers and nozzles. Microsoft Excel was used to calculate the 90th percentile as a percentage of the application rate at each distance. The 90th percentile was calculated from all available individual values per distance [8]. Using 10 collectors at 5 m distance and nine valid measurements, 90 collectors were used to calculate the 90th percentile for the 5 m distance.

In Germany, the statements on spray drift reduction are based on the median. This statement is necessary for the use of some pesticides, because some pesticides are only used with techniques which are listed in the "descriptive list of drift reduction". This method is described in JKI Guideline 2–2.1, which also describes the procedure for listing plant protection products in the spray drift reduction section of the inventory of pesticides [9]. This method is also used for biocidal products in this study. The first steps consist of calculating the median, forming a regression line according to the least squares method and using the regression function to calculate the adjusted medians. Based on this adjusted median, a reduction of 50%, 75%, 90% and 95% is then calculated. These reductions represent the reduction classes in Germany. The combination of sprayer and nozzle is assigned to the reduction class that is above the measured values in the entire range.

The weather conditions during the application were measured with a frequency of 1 Hz. Microsoft Excel and R version 4.1.1 with the "stats" package were used to check the validity of these data and to calculate mean values and standard deviations (Table 2).

Results

Meteorological conditions during the applications

The meteorological conditions during the applications corresponded to the guidelines of the JKI [6]. During the trials with cannon sprayer AirMix 110-05, the mean wind speed was 4.78 m s^{-1}, the mean air temperature was 21.1 °C and the mean relative humidity was 45.9%. During the trials with cannon sprayer ID-120-05 POM, the mean wind speed was 4.90 m s^{-1}, the mean air temperature was 22.3 °C and the mean relative humidity was 68.6%. All eight measurements carried out were within the tolerance range according to the JKI guideline 7-1.5 and were therefore valid (four repetitions per nozzle type). The meteorological conditions during application split by replication are shown in Table 1.

Spray drift of cannon sprayers with different nozzle types

Figure 3 shows the measured spray drift values of all tests with a cannon sprayer AirMix 110-05 and ID-120-05 POM. For both variants, the tracer was still found at the maximum distances of the trials, however, the spray drift decreases with increasing distance. The median. test shows at all distances that the spray drift differs significantly with cannon sprayer AirMix 110-05 and with cannon sprayer ID-120-05 POM. Significantly higher spray drift values were found with cannon sprayer AirMix 110-05. Thus, the cannon sprayer ID-120-05 POM had the significantly lowest spray drift values at all distances.

Table 2 Weather conditions recorded during the application, split by replicate

Sprayer and nozzle	Rep	Temperature		RH		Wind speed			Wind direction	
		Mean	Δ	Mean	Δ	Min	Max	Mean	Wind deviation[a]	Wind not centered[b]
		°C	°C	%	%	m s^{-1}	m s^{-1}	m s^{-1}	°	% > 45°
Cannon sprayer AirMix 110–05	1	20.7	0.11	63.5	0.32	3.10	8.90	5.87	− 23.30	7.62
	2	21.1	0.09	63.4	0.59	1.50	7.40	3.94	2.3	0.90
	3	20.7	0.11	64.5	0.36	1.50	6.70	4.02	− 1.8	2.3
	4	21.8	0.12	61.3	0.53	1.90	7.80	5.27	− 4.4	11.0
Cannon sprayer ID-120-05 POM	1	23.2	0.08	52.4	0.37	2.50	7.00	4.63	− 1.9	3.2
	2	24.3	0.19	44.4	0.62	1.70	9.10	4.63	− 26.2	14.9
	3	24.3	0.18	42.0	0.47	3.20	10.8	6.17	− 19.0	3.6
	4	23.6	0.05	44.7	0.71	1.90	7.10	4.15	25.2	14.03

[a] The mean wind direction must not deviate more than 30° from the perpendicular to the direction of travel

[b] No more than 30% of the individual values may deviate more than 45° from the perpendicular to the direction of travel

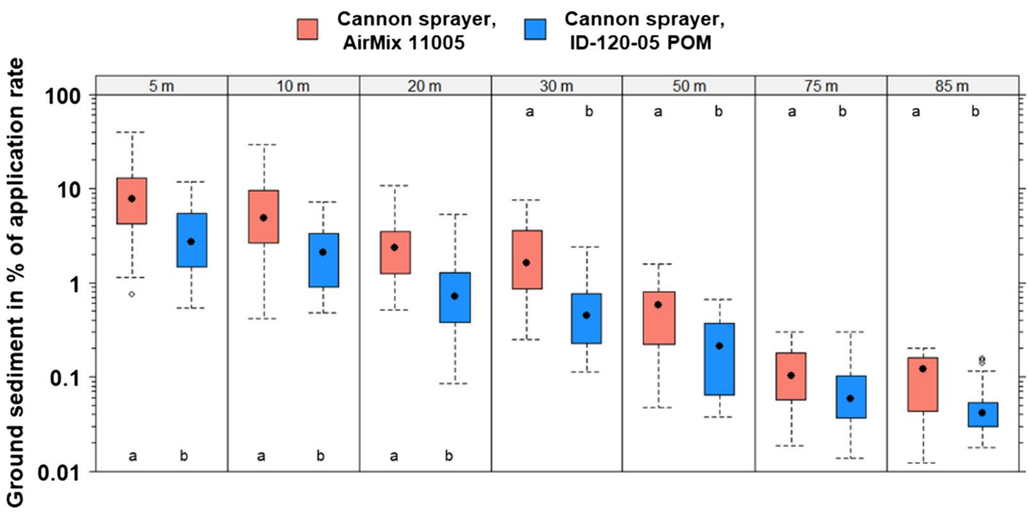

Fig. 3 Measured values of spray drift in percentage of application rate with a cannon sprayer using AirMix 110-05 and ID-120-05 POM depending on the distance to the treated area. Different letters indicate significant differences between the techniques within the distance (median.test, α = 0.05)

Comparison with basic drift values

Figure 4 shows the comparison between the spray drift value measured in this study as the 90th percentile and the basic drift values for a cannon sprayer with pneumatic atomisation of ECHA [11]. Compared to the pneumatic cannon sprayer, the spray drift values of the cannon sprayer ID-120-05 POM was well below the basic drift values over the entire distance. Close to the treated area, the spray drift values were up to three times lower (at 5 m: 14.91% vs. 7.29%). At a distance of 75 m from the treated area, the values were six times lower (1.2% vs. 0.2%). When using the cannon sprayer AirMix 110-05, only the spray drift values in the close range to the treated area were above the basic drift values of the pneumatic cannon sprayer and at a distance of more than 20 m they decreased below the basic drift values of the pneumatic cannon sprayer and approached the 90th percentile of the cannon sprayer ID-120-05 POM.

Spray drift classes and classification of the tested sprayers and nozzles

Figure 5 shows the spray drift reduction classes of the pneumatic cannon sprayer compared to the adjusted medians of the cannon sprayers AirMix 110-05 and the cannon sprayer ID-120-05 POM. The cannon sprayer AirMix 110-05 is just below the median of the pneumatic

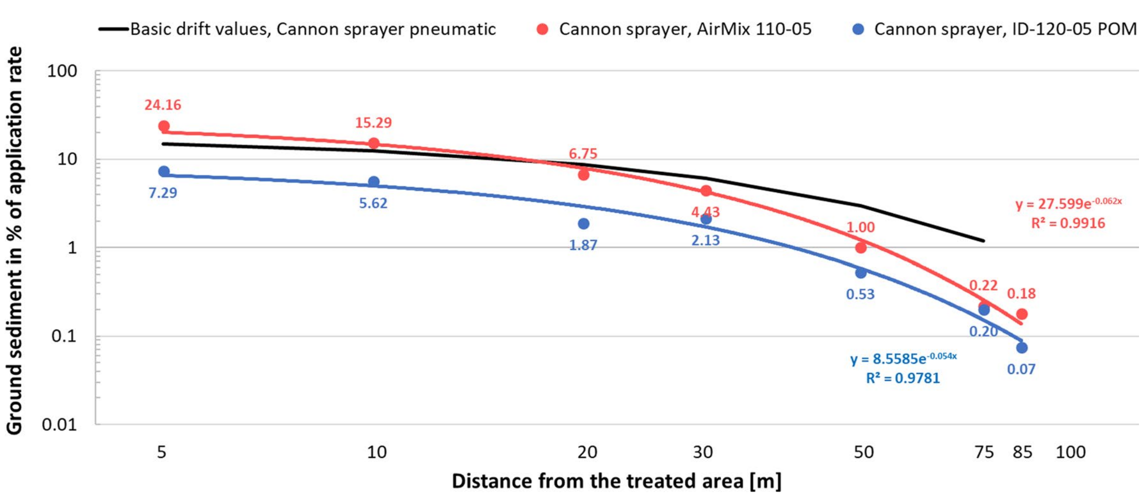

Fig. 4 90th percentile of the cannon sprayer with AirMix 110-05 and ID-120-05 POM compared to the basic drift values of the pneumatic cannon sprayer from ECHA [11]

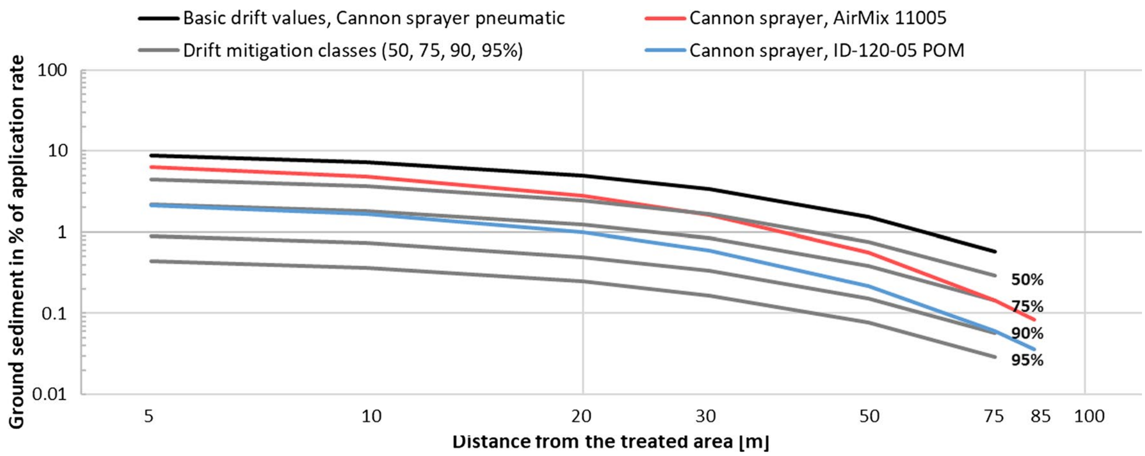

Fig. 5 Spray drift reduction classes (50%, 75%, 90% and 95%) of the pneumatic cannon sprayer and adjusted medians of the cannon sprayer AirMix 110-05 and ID-120-05 POM for classification of spray drift reduction

cannon sprayer in the close range of the treated area. Only at a distance of 30 m from the treated area is the cannon sprayer AirMix 110-05 below the 50% spray drift reduction class. However, for a classification, the values must be below a class limit over the entire measuring range. Therefore, no classification into a spray drift reduction class is possible for the cannon sprayer AirMix 110-05. The situation is different for the cannon sprayer ID-120-05 POM. The cannon sprayer ID-120-05 POM is below the spray drift reduction class of 75% in the entire measuring range and can be classified in this class.

Discussion and conclusion

The initial studies to measure the spray drift potential of sprayers and nozzles for the application of biocidal products were conducted by Langkamp-Wedde et al. [10]. In large-scale studies, spray drift was measured with a helicopter, an unmanned aerial vehicle and a cannon sprayer at the edge of a forest, a solitary tree and an avenue, and recommendations for basic drift values were issued. These basic drift values are the initial values determined in this field and have been accepted by the EU member states [11]. These values, established for a pneumatic cannon sprayer on the avenue, were used in the present study to compare with the spray drift of a hydraulic cannon sprayer.

In the absence of comparable studies, examples from plant protection must necessarily be used to evaluate the data. However, this is not easy, because in the biocide sector different techniques may be used than in plant protection and this leads to misinterpretation of the data. Here is an example. The treatment of an oak avenue with cannon sprayers has high spray drift values compared to the use of pesticides in vertical crops, such as orchards. While the basic drift value for the application of pesticides in orchards is 8.41% of the application rate at 5 m from the treated area [8], the pneumatic cannon sprayer achieves a basic drift value of 14.19% of the application rate at 5 m from the treated area. This is due to the fact that the target area for OPM control is much higher compared to applications in orchards. The habitat of the caterpillars is often restricted to the treetops [2], so droplets have to travel long distances and cannon sprayers that can reach these heights are often used. This is not necessary in orchards. Orchard sprayers, like air-assisted sprayers, are used there, which are less susceptible to spray drift. A comparison of the spray drift values measured in this study with the basic drift values for plant protection products as a reference sedimentation curve, as in a study by Grella et al. [19], is therefore not helpful. However, the determination of basic drift values for biocide application technologies is of great importance. The study by Grella et al. [19] shows what can happen when non-optimal comparative values are used. In this study, an air-assisted sprayer equipped with a cannon sprayer was used in both mature and young poplar (*Populus* spp.) plantations. They found that Venturi nozzles (TVI8004 Air Injection Hollow Cone Nozzle) achieved the highest spray drift reduction of 86% between 40 and 47 m from the treated area. However, the reference spray drift curve used was from late-growing orchards by Rautmann et al. [8]. The maximum tree height in orchards is about 4 m and air-assisted sprayers with axial fans are often used [20]. Mature poplar orchards were 18 m high and young poplar orchards were 6 m high [19]. This makes it very difficult to compare the spray drift potential between orchards and poplar plantations when both the habitus and the technique used cannot be compared.

In the present study, the hydraulic cannon sprayer with ID-120-05 POM nozzles shows lower spray drift values compared to the pneumatic cannon sprayer. However, it should be noted that different tractor tracks and spray angles were used in the two studies. According to Langkamp-Wedde et al. [10], the tractor track with the pneumatic cannon sprayer was close to the trunk of the trees and the liquid was sprayed into the crown from the windward side from below. In the present study, the spray tube of the hydraulic cannon sprayer was not set at 90° but only at 75° for technical reasons. Therefore, the contractor could not drive exactly in the same lane, but drove 15 m beside the avenue and the liquid was sprayed into the crown at an angle of 75° on the windward side. The influence of the tractor track and the spray angle on the spray drift cannot be answered within the scope of this study. Measurements with both sprayers on both tractor tracks are missing. However, a comparison with other studies is possible. Grella et al. [19] used two different orientations of the spray tube in their study. The spray tube was oriented vertically (90°) and tilted at 40°, and the authors found that spray drift was lower when a vertical orientation was used. This result suggests that the vertical application of a pneumatic cannon sprayer is already a best-case scenario in terms of spray drift potential, compared to a lower application angle. If the pneumatic cannon sprayer in the study by Langkamp-Wedde et al. [10] had used the same lane and lower spray angle as the hydraulic cannon sprayer in the present study, the spray drift may have been even higher with pneumatic atomisation. It can therefore be concluded that the lower spray drift potential when using the hydraulic cannon sprayer is not due to the different lanes, but to the type of atomisation.

Furthermore, differences in spray drift potential were also found between the nozzles used. The clear differences between the nozzles can be explained, among other things, by the different droplet sizes. The smaller the droplets, the further they can drift and the coarser the droplets, the lower the spray drift potential [21–24]. The number of coarse droplets is higher in ID-120-05 POM than in AirMix 110-05. In contrast, the number of droplets smaller than 100 µm is almost identical in both nozzles. This could be the reason why the spray drift values of AirMix 110-05 drop almost to the level of ID-120-05 POM at a distance of 50 m from the treated area. That the droplet size has a high influence on the spray drift behaviour is not a new finding and has been studied a lot in the field of plant protection [23, 25–28]. The fact that the cannon sprayer with its large blower does not influence the droplet size is already a new finding, which is of great importance in the biocide sector for the control of the oak processionary moth. This makes it possible to test other types of nozzles in order to expand the use of the cannon sprayer in the biocide sector.

Spray drift can also be influenced by weather conditions, especially wind speed, temperature, relative humidity and atmospheric stability [21, 29–31]. Field spray measurements and subsequent modelling have shown that conditions with different air temperatures and relative humidity at constant wind speeds influence the spray drift potential more than conditions with different wind speeds at constant air temperatures and relative humidity. According to these studies, an increase in air temperature from 13.4 °C to 21.7 °C and a decrease in relative humidity from 90 to 40% lead to an increase in spray drift potential from 4 to 10% at 1 m from the treated area [31]. Nuyttens et al. [31] observed the greatest impact due to decreasing relative humidity up to 5 m from the treated area. At a distance of 5 m from the treated area, a decrease in relative humidity from 60 to 40% increased the spray drift potential by less than 1%. This is because the droplet diameter gradually decreases as the water contained in the droplet evaporates [30, 32–34]. In the present study, the influence of decreasing relative humidity on the amount of spray drift could not be observed. The field tests with a hydraulic cannon sprayer and two different nozzles were carried out on the same day. The measurements with the AirMix 110-05 nozzle were made in the morning and the measurement with ID-120-05 POM in the afternoon. During the day, the weather conditions were constant except for the relative humidity. The relative humidity increased from 63.2 to 45.9% during the day. According to Nuyttens et al. [31], droplet size was probably smaller and spray drift potential higher in the afternoon due to lower humidity. In this study, spray drift values measured when using the ID-120-05 POM nozzles in the afternoon at lower relative humidity were consistently lower than when using the AirMix 110-05 nozzles in the morning. Combined with the lower relative humidity in the afternoon, this means that the potential of the ID-120-05 POM to reduce spray drift could be even higher.

In summary, this study shows that biocidal products drift into non-target areas during OPM control with a cannon sprayer. However, the results also show that there are already established ways to reduce spray drift by 75% by choosing the least drift-prone technology. This can be done through the choice of nozzles, among other things, and can have a major impact on the spray drift of biocidal products into the environment and lead to better protection of biodiversity. To promote this, it is important to develop a regulatory framework similar to that already in place for pesticide application devices. Determining basic drift values should therefore be a top priority to characterise the technologies currently in use. The risk of spray drift into non-target areas can only be reduced as much as possible if there is more knowledge about the spray drift potential of the devices used.

Abbreviations

$D_{v0.1}$	10% Of spray liquid volume fraction is made up of droplets smaller than this value
$D_{v0.5}$	Volume median diameter
$D_{v0.9}$	90% Of spray liquid volume fraction is made up of droplets smaller than this value
ECHA	European Chemicals Agency
ISO	International Organization for Standardization
JKI	Julius Kühn Institute
OPM	Oak processionary moth
V_{100}	Volume fraction of droplets smaller than 100 µm (%)

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Author contributions

TLW planned and organised the fieldwork, calculated and selected statistical models, prepared tables and diagrams, conducted the literature review and wrote the manuscript. DR was involved in organising the fieldwork and helped with the study organisation and design. JUN discussed the results and commented on the manuscript. DvH and JKW supervised the project. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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