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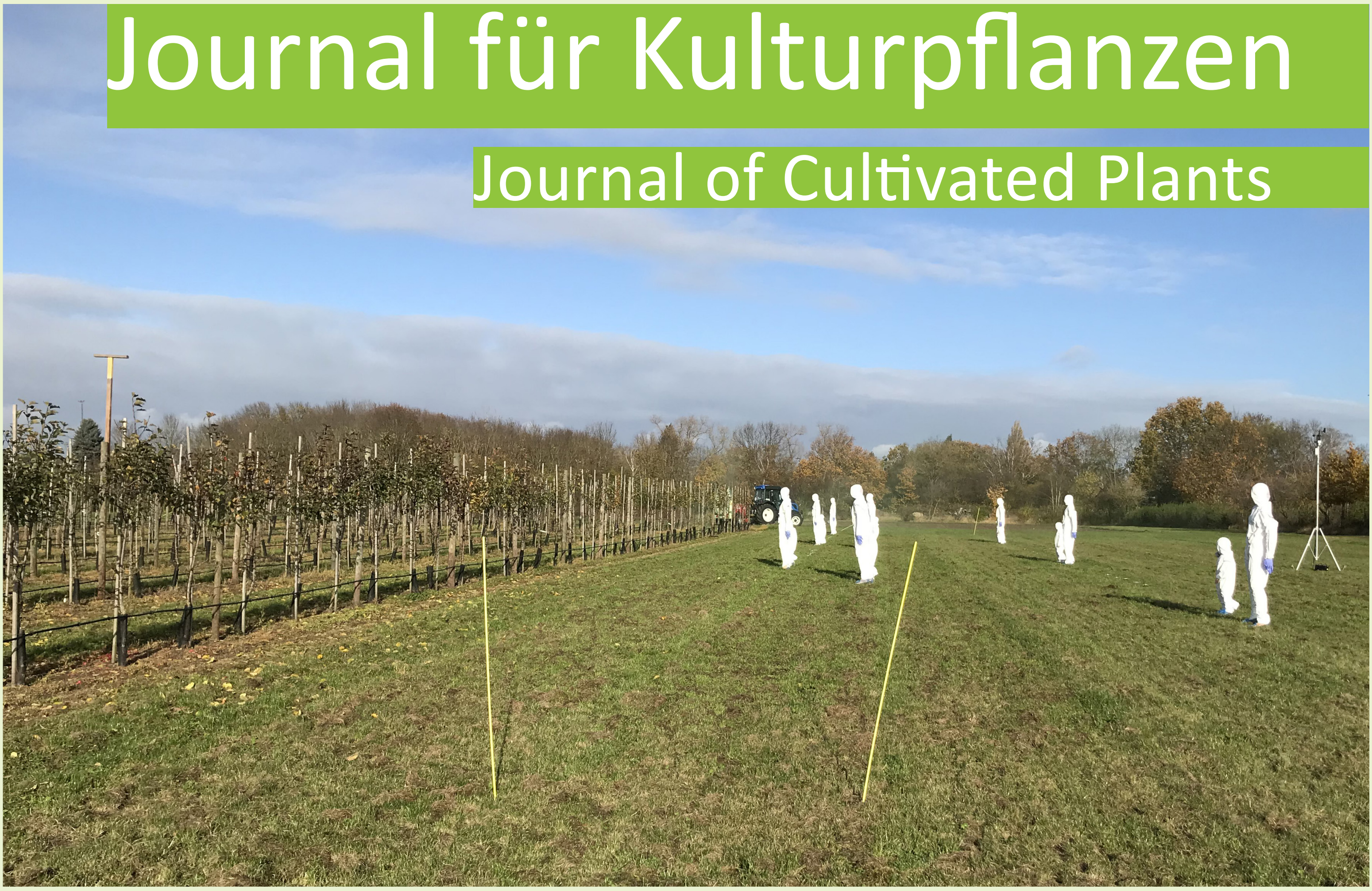

Spray drift and exposition

Julius Kühn-Institut
Bundesforschungsinstitut für Kulturpflanzen
Federal Research Centre for Cultivated Plants

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Die Dosis und das Gift

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Als Leser dieses Journals gehe ich davon aus, dass Sie auch die Tagesmeldungen verfolgen. Sie kennen sicherlich die Berichte, dass mal wieder irgendetwas im Boden, im Grundwasser, im Blut oder in sonstigen Kompartimenten der Umwelt oder des Daseins „gefunden“ wurde. Wir alle wissen: „only bad news are good news“ und können solche Meldungen dann auch entsprechend einordnen. Zumal die heutige Analysetechnik mittlerweile so leistungsfähig ist, dass jedwede Spuren von Stoffen in noch so kleinen Dosen analytisch bestimmt werden können. Die wirklich spannende Frage ist doch aber, ob von der bloßen Existenz eines Stoffes auch unmittelbar ein Risiko ausgeht? Schon Paracelsus wusste: „Alle Dinge sind Gift, und nichts ist ohne Gift; allein die Dosis machts, dass ein Ding kein Gift sei.“[1]

Um die Frage nach dem Gift wissenschaftlich richtig einordnen zu können, gibt es das System der Risikobewertung. Hier sitzen Experten an Messdaten und Modellen, die bewerten, ob die bei einer Anwendung auftretende Exposition von Stoffen in der Umwelt oder in Bezug zur Gesundheit auf toxikologischer Basis kritisch einzustufen ist oder nicht. Es geht also nicht nur darum, ob etwas gefunden werden kann, sondern vielmehr um die Frage, ob die zu findende Menge nach aktuellem Stand der Wissenschaft ein tatsächliches Risiko darstellt. Nach diesen Kriterien findet u. a. auch die Bewertung von Pflanzenschutzmitteln im Rahmen des Zulassungsprozesses statt.

Wie jedes Modell, sind auch die zur Risikobewertung von Pflanzenschutzmitteln nur so gut, wie die getroffenen Annahmen und die Daten auf denen sie gründen. Inhaltlich geht es dabei z. B. um die Bewertung von Risiken, die durch das Verdriften von Pflanzenschutzmitteln bei der Ausbringung entstehen. Der Experte spricht hier von der Exposition auf sogenannten Nicht-Zielflächen. Das sind Strukturen, wie beispielsweise Hecken, Gräben und Wege, die das zu behandelnde Feld ggf. umgeben. Ein anderes Beispiel ist die inhalative und dermale Exposition von Anwendern, Anwohnern und Nebenstehenden (= Amtsdeutsch für Spaziergänger, Fahrradfahrer, Autofahrer, die mit ihrem Hund spazieren gehen etc.). Um all diese Dinge verlässlich und realitätsnah bewerten bzw. modellieren zu können, braucht es Daten. Aber, wo kommen diese Daten her? Nach welchen Methoden werden diese erhoben? Sind die Methoden zur Erhebung der Daten eigentlich realitätsnah? Wer macht sowas überhaupt?

Um diese Fragen zu beantworten, haben wir dieses Themenheft zusammengestellt, um Ihnen den Blick hinter die Datenkulisse zu eröffnen. In dieser Ausgabe dreht sich daher alles um neue Methoden zur Erhebung von Expositionsdaten für unterschiedlichste Anwendungsfälle, um die Modelle der Risikobewertung mit möglichst realitätsnahen Daten zu füttern. Erlauben Sie mir zum Schluss noch folgenden Hinweis: Da Sie wissen, dass die Dosis relevant ist, konsumieren Sie bitte nicht alle Beiträge auf einmal!

[1] Theophrast Paracelsus: Werke. Bd. 2, Darmstadt 1965, S. 508-513, URL: http://www.zeno.org/nid/20009261362

Journal für Kulturpflanzen, 75 (05-06). S. 130–137, 2023 | DOI: 10.5073/JfK.2023.05-06.02 | Molnar et al.

Gabor Molnar[1], Katrin Ahrens[1], Jens Karl Wegener[1], Markus Röver[2], Enrico Peter[3], Sabine Martin[2], Sebastian Dittmar[4]

Development of a selective testing method to pesticide aerosols for characterization and comparison of agricultural tractor cabs classified according to EN 15695-1

Entwicklung eines selektiven Prüfverfahrens zu Pflanzenschutzmittel-Aerosolen zur Charakterisierung und zum Vergleich von landwirtschaftlichen Traktorkabinen, klassifiziert nach EN 15695-1

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Abstract

Only preliminary results from tactile tests are currently available on the exposure-reducing effect of different tractor cabs according to EN 15695-1. Scientifically reliable data are not available. To close this gap, a project was initiated by the Federal Office for Consumer Protection and Food Safety (BVL) and by the Social Insurance for Agriculture, Forestry and Horticulture (SVLFG) – with the participation of the Federal Institute for Risk Assessment (BfR). Due to the expertise and the available technical facilities (machinery and laboratories), corresponding tests were carried out by the Institute for Application Techniques in Plant Protection at the Julius Kühn Institute (JKI), Federal Research Centre for Cultivated Plants. As part of the project, data was collected to enable a well-founded review of the management decision on the protective effect of the different type of cabins mentioned in EN 15695-1. The current paper gives an overview about the methodology developed for gathering the data.

Keywords

plant protection, agricultural tractor cabs, EN 15695-1, protective level, testing method

Zusammenfassung

Zur expositionsmindernden Wirkung von verschiedenen Schlepperkabinen nach EN 15695-1 liegen derzeit nur vorläufige Ergebnisse aus Tastversuchen vor. In wissenschaftlicher Hinsicht belastbare Daten sind nicht verfügbar. Um diese Lücke zu schließen, wurde ein Projekt durch das Bundesamt für Verbraucherschutz und Lebensmittelsicherheit (BVL) und durch die Sozialversicherung für Landwirtschaft, Forsten und Gartenbau (SVLFG) – unter der Beteiligung des Bundesinstituts für Risikobewertung (BfR) – initiiert. Aufgrund der Expertise und der vorhandenen technischen Einrichtungen (Maschinen und Labore) wurden die entsprechenden Untersuchungen durch das Institut für Anwendungstechnik im Pflanzenschutz am Julius Kühn-Institut (JKI), Bundesforschungsanstalt für Kulturpflanzen, durchgeführt. Im Rahmen des Projektes sollten Daten erhoben werden, welche eine fundierte Überprüfung der Managemententscheidung zur Schutzwirkung der genannten Kabinen nach EN 15695-1 ermöglichen. Der Artikel beschreibt die für die Datengenerierung entwickelte Methodik.

Stichwörter

Pflanzenschutz, landwirtschaftliche Schlepperkabinen, EN 15695-1, Schutzniveau, Prüfverfahren

Introduction

In the context of the authorization of plant protection products, the necessary personal protective equipment (PPE) for operators is determined based on a risk assessment for each individual plant protection product (PPP). PPE is required where the personal exposure of the operator can be reduced to a level where unacceptable health risks can be excluded. The specific requirements for PPE are issued within the authorization and can be found in the instructions for use of the product.

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In 2017, application directive SB199 was announced. Exceptions for the wearing of PPE are defined for the operator when the machine used for the application of plant protection products is equipped with a category 3 or category 4 cab according to EN 15695-1. The announcement led to controversial discussions in which it became clear that many operators were not aware that they may need to wear PPE in a closed cab if their cabin does not correspond to the protection level of a category 3 or category 4 cabin. One result of this discussion was that the exceptions to wear PPE should be extended to other types of cabins.

According to expert's estimates, even closed cabins that have been labeled category 2 on the basis of EN 15695-1 and non-certified cabins that are sufficiently airtight and have air conditioning with filtered air supply (category 2* defined by BVL) provide adequate protection against PPPs during the application process. Therefore, they could be used without further PPE measures in many cases.

However, only results from preliminary tests on the exposure-reducing effect of unclassified tractor cabins are currently available. Scientifically reliable data are not available. Within the framework of field tests, it should be clarified whether category 2 cabins or comparable non-classified or non-certified cabins (category 2*) provide a sufficient level of protection under practical conditions, so that even when using these types of cabin, the PPE for protection against dermal exposure (protective suit and gloves) can be dispensed within the cabin. In this context, adequate protection means that the exposure is significantly lower than that of an unprotected driver (category 1) and not significantly higher than in category 3 or 4 cabins.

Against this background, the Federal Office for Food Safety and Consumer Protection (BVL) initially modified application directive SB199 to equate category 2 and 2* cabins with category 3 and 4 cabins for a transitional period. During this transitional period, experiments are carried out to investigate the protective effect of different cabin categories in the application of PPP under practical conditions, in order to evaluate the BVL's decision retrospectively. To this end, a joint research project was initiated in cooperation with the BVL, the Federal Institute for Risk Assessment (BfR), the Social Insurance for Agriculture, Forestry and Horticulture (SVLFG) and the Julius Kühn Institute (JKI).

According to the project plan the JKI collected current, relevant experimental data on dermal and inhalation exposure on tractors without a cabin and in closed tractor cabins in accordance with the test conditions agreed with the project partners. The aim of the tests was primarily to compare exposure values (and therefore the comparison of the protective effect) for test persons in different settings, like tractor with cat. 1, cat.2, cat. 4 cabins according to EN 15695, as well as not-certified cat. 2* cabin (a tight closing cabin with air condition and dust filter system) according to BVL classification (BVL, 2020). Aim of the paper is to describe the development and the final methodology in detail.

Development of an adequate testing method

During preliminary tests within the project, it became obvious that only very low levels of exposure are to be expected inside the vehicle´s cabin. Therefore, suitable dosimeter materials and measuring methods for the quantitative determination of these small amounts had to be established. Furthermore, based on the results of the mentioned preliminary tests it was agreed that the practical tests should be limited with a focus on orchard spraying as a worst-case scenario.

The applied analytical methodology

There are already established methods for testing and evaluating the performance of filter systems, which are described in various standards (fine and coarse dust filters according to DIN EN ISO 16890:2017 and particulate filters according to DIN EN 1822:2019 and DIN EN ISO 29463:2019). These methods focus on the question, how well a filter system is suitable for removing certain particle sizes from the air flow. In order to measure the quality of the filter system, particle counters are usually used behind the filter unit. These measurement systems record the total amount of particles (e. g. consisting of dust and soot particles as well as aerosols, etc.) in an undifferentiated manner. However, the aim of our research is only quantifying the amount of spray liquid of a PPP passing through the filter system as an aerosol. To achieve this goal a selective measurement method is required to determine the exposure of the operator. For this purpose, the widely used standard drift measurement method of JKI (JKI, 2013) was adapted. With a defined dye solution as a surrogate for spray liquid (Herbst & Wygoda, 2006), the exposure outside the cabin as well as the exposure for the operator inside the cabin was determined.

In addition to the test method, the applicability of the different dosimeter materials was verified by measuring blank values (Fig. 1) and recovery rates (Fig. 2). Furthermore, both the laboratory recovery and the field recovery are determined to detect any possible degradation of the applied fluorescent dye (pyranine) during the application process. To determine the recovery rates, the dosimeter material samples used are contaminated with a defined quantity of fluorescent dye solution (stock solution: 20 mg/l, pipetted volume: 50 µl, the outcome of this is: 1 µg/detector). The contaminated detectors – left outside next to the test site or within the cabin for the duration of the test – were protected from unwanted contamination. After the test runs, the recovery samples are packaged, stored and analysed like the measurement samples.

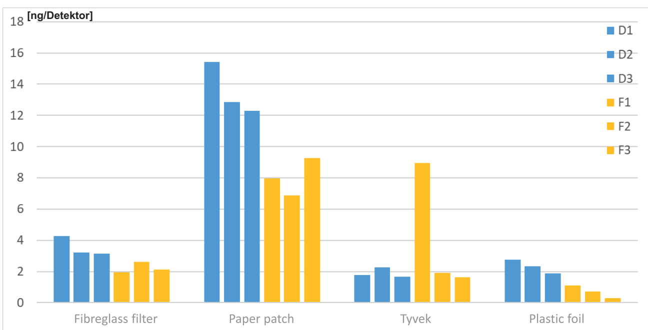
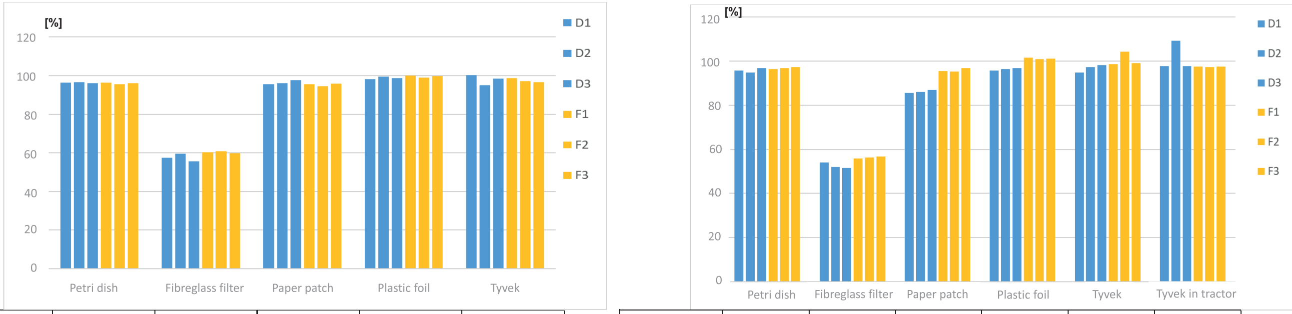


Fig. 1. Blank values of the applied target materials (blue and yellow represent two different trials, each with a triple repetition)



Labor recovery [%]	96.20	58.94	95.82	99.16	97.66
+/-	0.97	6.03	2.90	1.97	5.56

Field recovery [%]	96.37	54.45	91.07	98.84	98.75	99.55
+/-	2.81	6.68	16.26	8.15	9.50	14.23

Fig. 2. Laboratory recovery rate (left) and field recovery rate (right) of the applied target materials (blue and yellow represent two different trials, each with a triple repetition)

Dosimeter for detection of external contamination

In order to record the external contamination of the tractor cab, the construction shown in Fig. 3 was developed, implemented and tested. The measured values serve as reference values for external exposure during the spraying process. The auxiliary frame was developed in such a way that cross-contamination between the test repetitions can be effectively prevented and a fast and efficient test procedure is possible. By using the auxiliary frame, time consuming decontamination of the outer part of the cabin between the different test runs is not necessary. Five sets (six detector plates per set [see Fig. 3 left]) of exchangeable detector holder plates were manufactured, which means that five repeated measurements with different parameterizations can be carried out in a relatively short time.

Based on preliminary test results, the detector holder plates were equipped with three different detector materials (Herbst & Molnar, 2002):

– Paper patches
– Plastic foil
– Tyvek material

Despite the relatively high blank values (Fig. 1), the paper patches allow measuring high exposure values covering the range of exposure expected outside a cabin without the risk of filter saturation or dripping/dropping. Plastic foil and Tyvek, on the other hand, enable the reliable measurement of low exposures due to the high recovery rate and negligible blank values. Furthermore, the parallel use of three different detector materials at nearly the same position increases the statistical reliability of the measured values.

Dosimeter for detection of internal contamination

Because the preliminary tests within the project have clearly shown that only a very small amount of the applied spray liquid gets into the cabin, detectors should be developed that are able to detect these low levels of exposure inside the cabin. Three different detectors were used to determine the inhalation and dermal exposure. Figure 4 shows the systems implemented.

In order to determine the inhalation exposure within the cab, the sampler units of aerosol collection pumps were optimized. As a result, a very fine-pored nitrocellulose filter as well as a fibreglass filter with an increased effective detector surface area were used. The initial material tests had shown that nitrocellulose and fibreglass have good properties in terms of blank values and recovery rates from a laboratory point of view. The pore size of the filter is 0.22 µm, which allows collecting even smallest aerosol particles. The enlarged detector surface area allows for an increased collection efficiency and it causes only a small throttling of the airflow. All factors mentioned have an essential influence on the measurements.

During the development of a proper detector for dermal exposure, the aim was also to increase the active detector area. Instead of paper patches (fixed to the coverall of the driver) applied during the preliminary tests, Tyvek full-body coveralls and latex gloves were used. The Tyvek material also has another positive property: the amount of fluorescent dye collect-

Fig. 3. The realized detector holder plate (left) and the positioning of the different plates

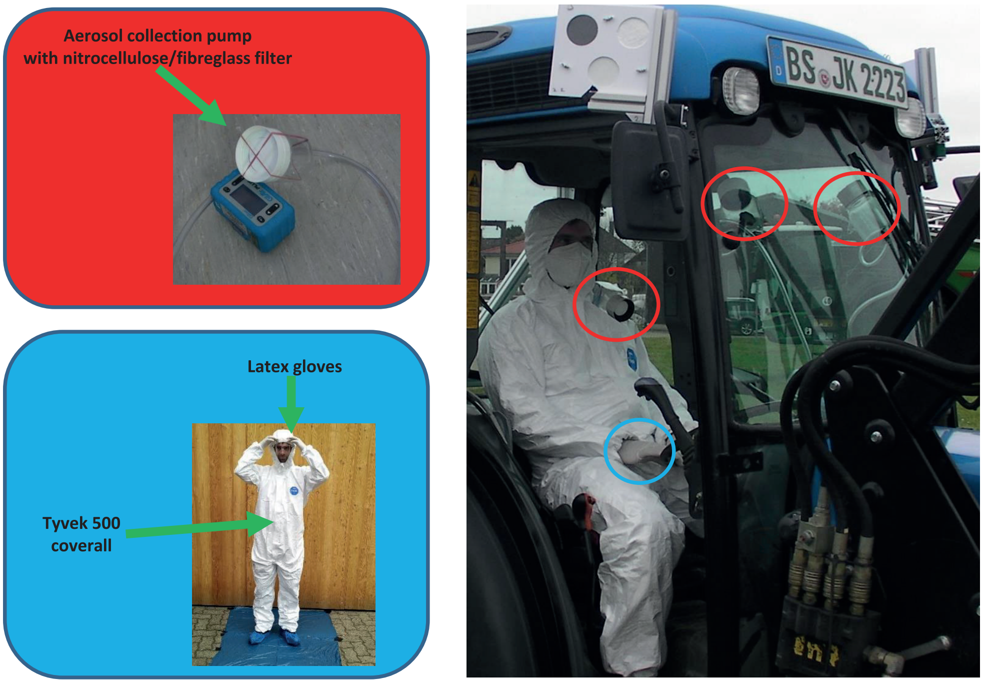


Fig. 4. The detectors and the placing of the detectors to measure exposure within the cabin

ed during the test runs can be removed from the surface with relatively little amount of washing liquid, which means that a sufficiently high concentration of the dye can be achieved, even with only very low exposure values. This enables a reliable determination of contamination in the lab phase. Furthermore, an additional detector (latex gloves) was used to record skin contamination on the hands – a particularly relevant risk factor.

Within the cabin, the orientation of the air fan inlet nozzles, the ventilation intensity and the placement of the detectors could be of importance in measuring exposure levels. To represent a "worst case" scenario, the ventilation is set to the highest level and the nozzles of the ventilation system inside are directed towards the driver´s head and the samplers of the aerosol collection pumps placed in the cabin. The applied volume flow for the aerosol collection pumps is 2 l/min, which is commonly used in exposure studies.

Measurements

As mentioned before, different types of tractors with different cabin categories were examined with regard to their exposure-reducing effect for operators (Fig. 5). Measurements with a tractor without a cabin (cat. 1) represent the reference value of 100% exposure for orchard spraying. For this setting, a Kramer KL400 equipped with only a roll-over bar was used. For the setting with a cat. 2* cabin according to BVL definition a New Holland TN 70 NA was used. Furthermore, a New Holland T4.100N was used. This tractor is equipped with a cabin concept according to EN 15695 and can be used both in cat. 2 or cat. 4 mode.

The relevant application parameters are as follows:

Orchard Sprayer: Wanner K1000
Speed: 7 km/h
Applied volume: ~75 l
Applied dose: 500 l/ha
Pressure: 10 bar
Nozzle: TeeJet TXA80015VK/Albuz ATR Yellow
Dye: pyranine
Dye concentration: 0.1 %
Test location: JKI test site, Messeweg Braunschweig

Figure 6 shows the spatial arrangement and Figure 7 the weather conditions. In order to identify any correlations, the weather parameters as wind direction and wind speed were

Cat. 1: **Kramer KL400** ***Cat.2/2*: New Holland TN 70 NA*** ***Cat. 2* and 3/4: New Holland T4.100N***

Fig. 5. The different tractor types under test

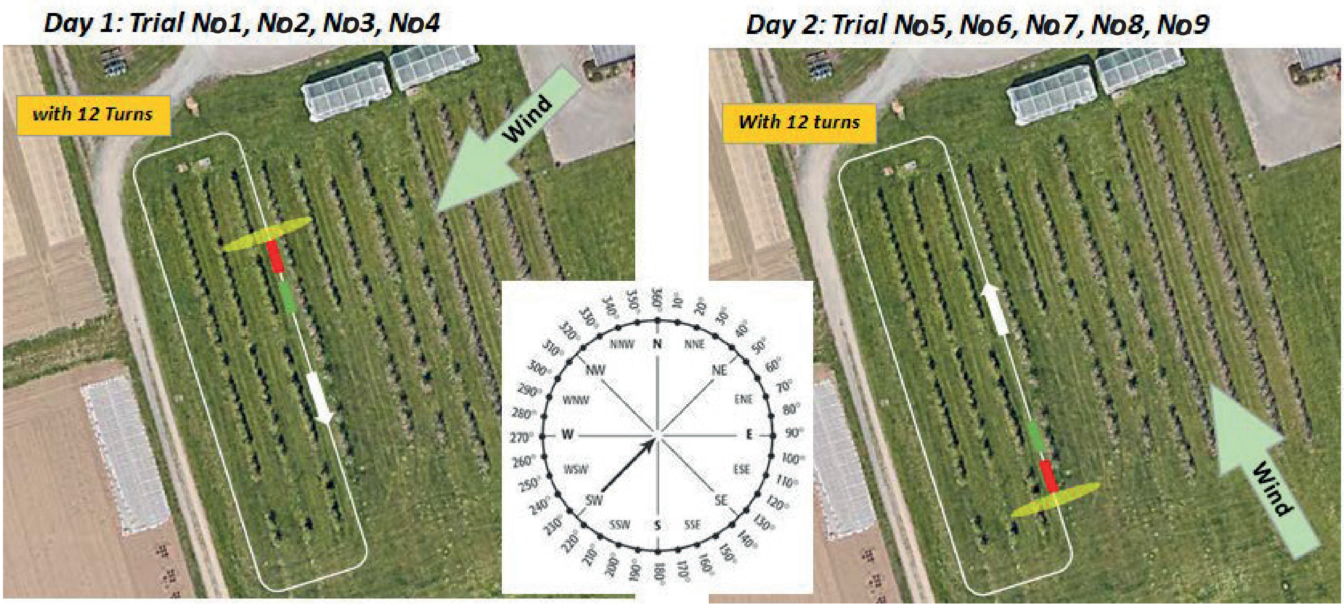


Fig. 6. The location of the measurements

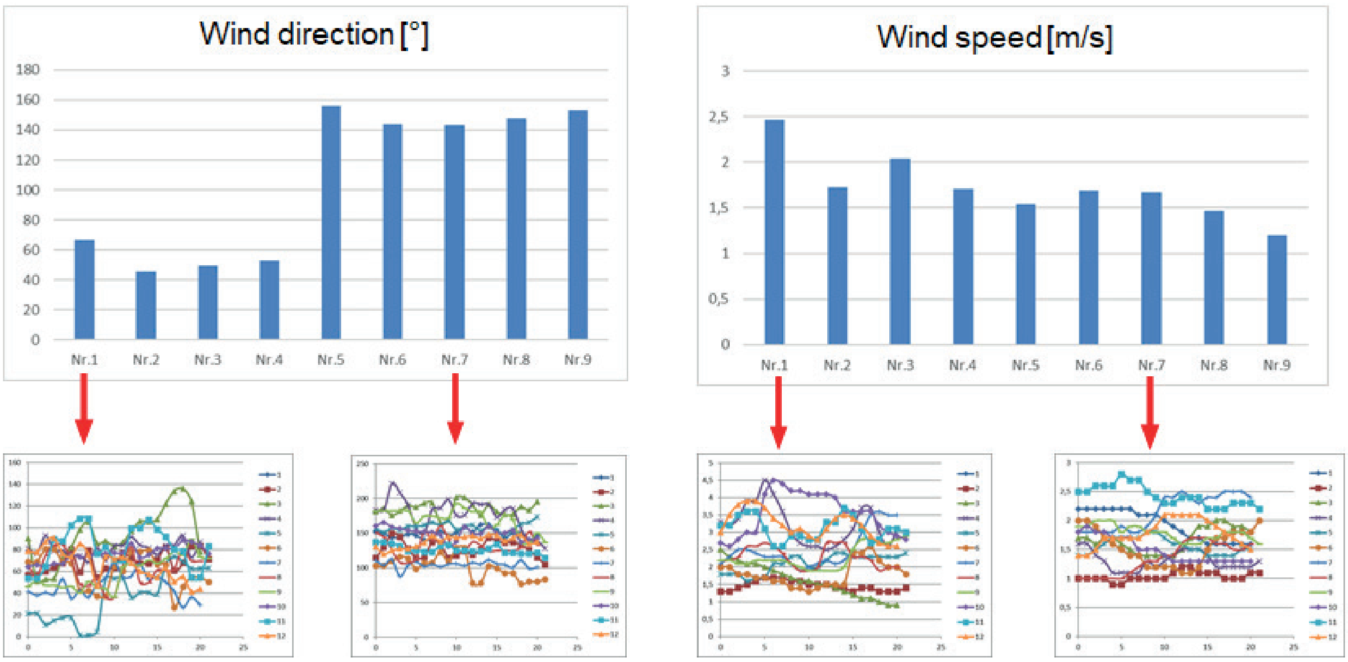


Fig. 7. The relevant weather conditions: the mean values for the trials (top) and the recorded values with high resolution exemplary for trial 1 and trial 7 (bottom)

logged synchronously with a repetition rate of 1 data point per second for each treatment process. During the application the tractor was moving in a circular course (Fig. 6). The trials were performed in four independent measurement campaigns.

Measurement results regarding external exposure

Figure 8 shows the exposure measured on the outside of the cabin. The local contamination values shown are mean values, they were calculated from the recorded contamination values of the individual detectors made of Tyvek, plastic foil and paper patches. The measured values of outside exposure represent the potential contamination for the operator inside the cab.

Measurement results regarding internal exposure

Figure 9 shows the measured dermal exposure values by using full body coveralls.

Figure 10 shows the exposure on the latex gloves used by the operator in the different test series.

Figure 11 shows the measured results using aerosol collection pumps in order to specify inhalation exposure of the operator.

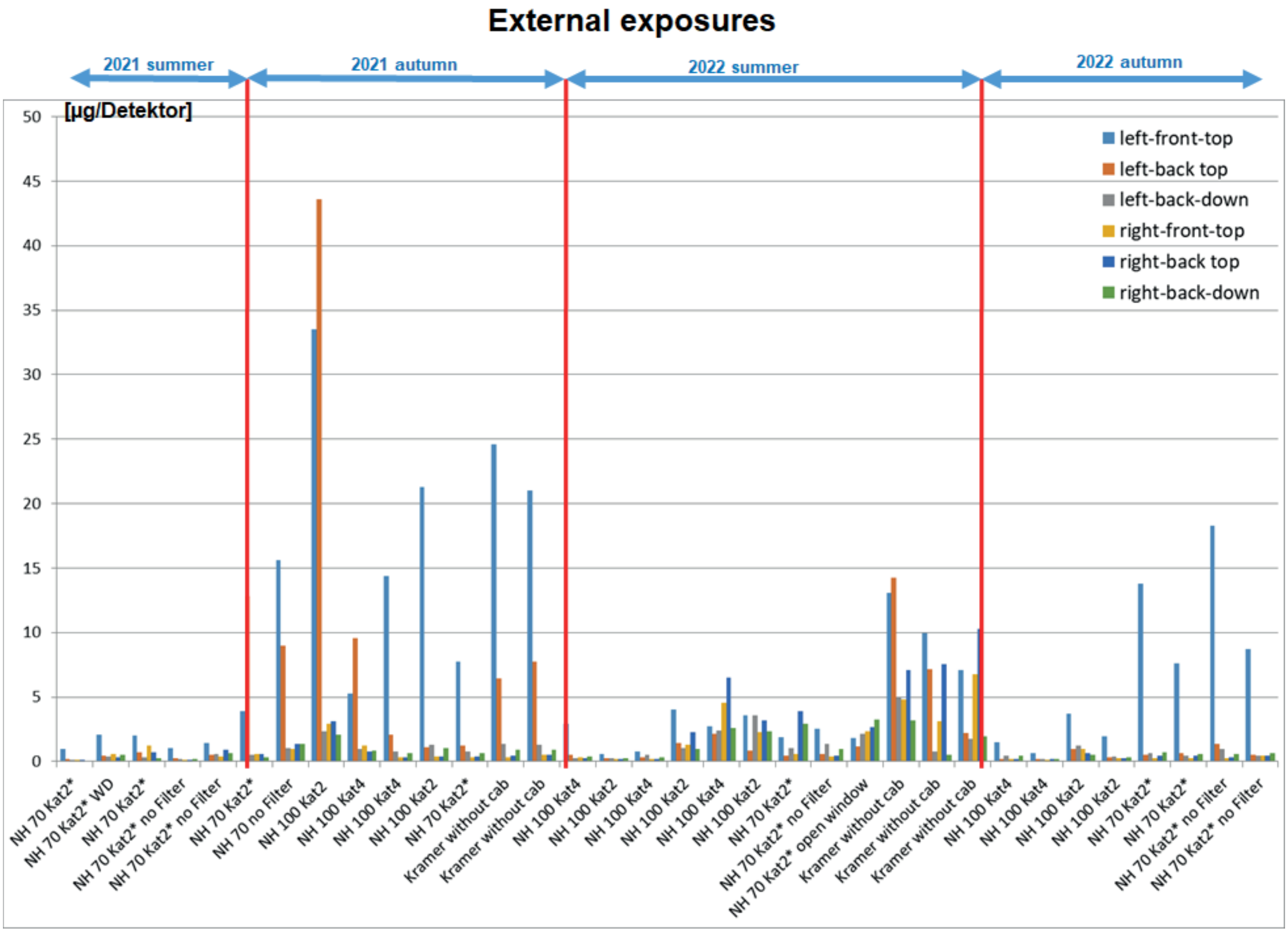


Fig. 8. The measured exposure values on different frame positions measured in different campaigns

Conclusion

The test methodology developed is based on an aqueous fluorescent dye solution acting as surrogate for spray liquid with PPP. Fluorimeter analysis of the dye on different dosimeters allows for the calculation of exposure towards the spray solution outside and inside the cab. Based on the analytical data it is possible to assess and characterize the protective effects of different cab categories on the operator. The data for outside, dermal and inhalation exposures show a wide range of amounts of dye that have to be robustly determined and quantified. The data for dermal and inhalation exposure of operators show that the developed methodology is able to detect very small amounts of dye solution/spray liquid that may get into the cabin through the ventilation system. The utilization of different dosimeters for outside exposure also contributes to the number of repetitions, which can be gained in one test run, allowing for a higher statistical power. The methodology is close to spraying in practice. The use of an airblast sprayer represents a worst case scenario for exposure assessment. Moreover, it is not depending as much on default weather conditions as compared to drift measurements (concerning wind speed and wind direction).

Conflicts of interest

The authors declare that they do not have any conflicts of interest.

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BVL, 2020: Fachmeldung: Einsatz von dicht schließenden Fahrerkabinen mit Luftfiltration im Pflanzenschutz. URL: https://www.bvl.bund.de/SharedDocs/Downloads/04_Pflanzenschutzmittel/00_fachmeldungen/pdf_Fachmeldung_Fahrzeugkabinen_20200108.pdf?__blob=publicationFile&v=3, Access: 28 February 2023.

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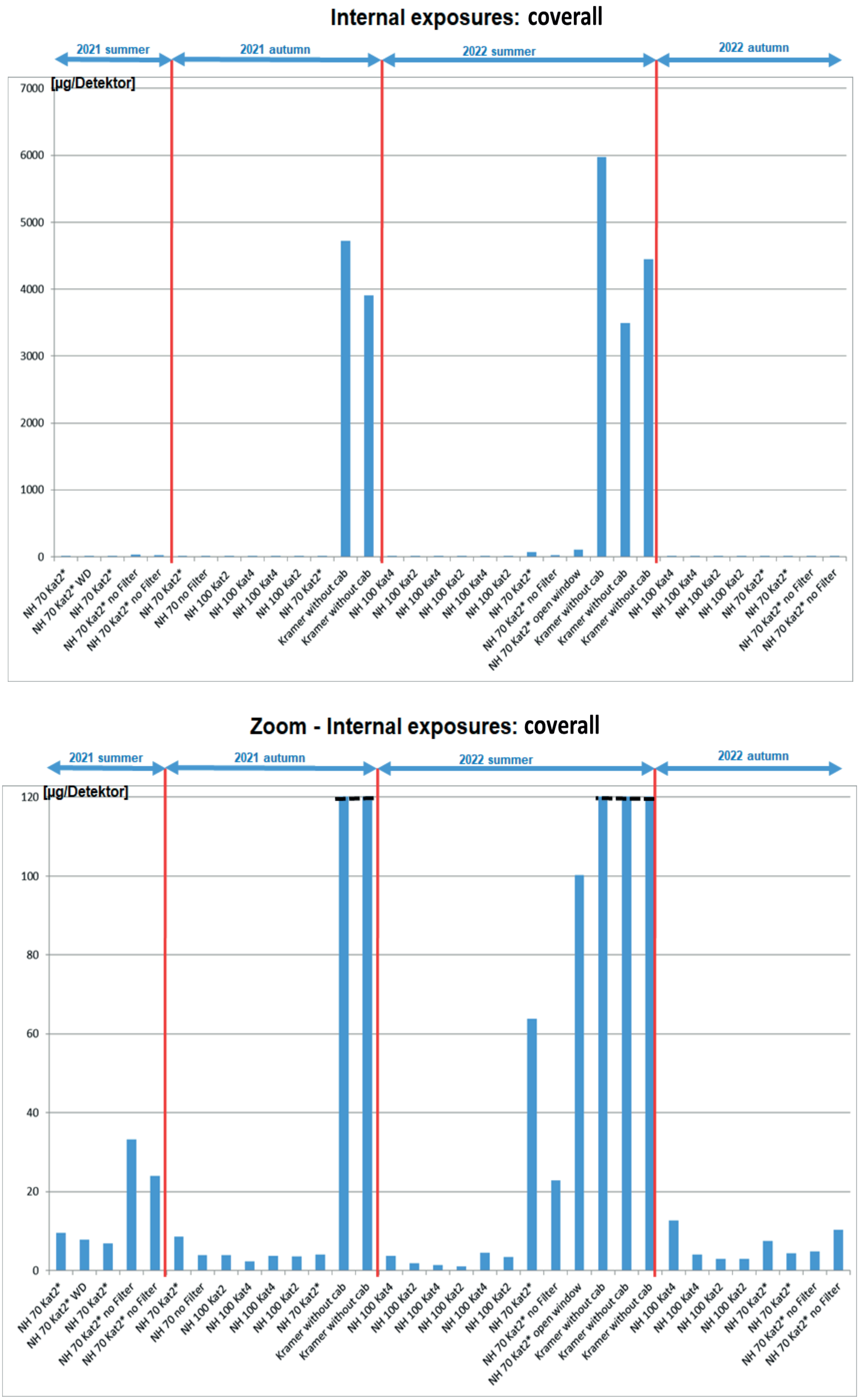

Fig. 9. Measured contamination values regarding dermal exposure (with zoom bottom).

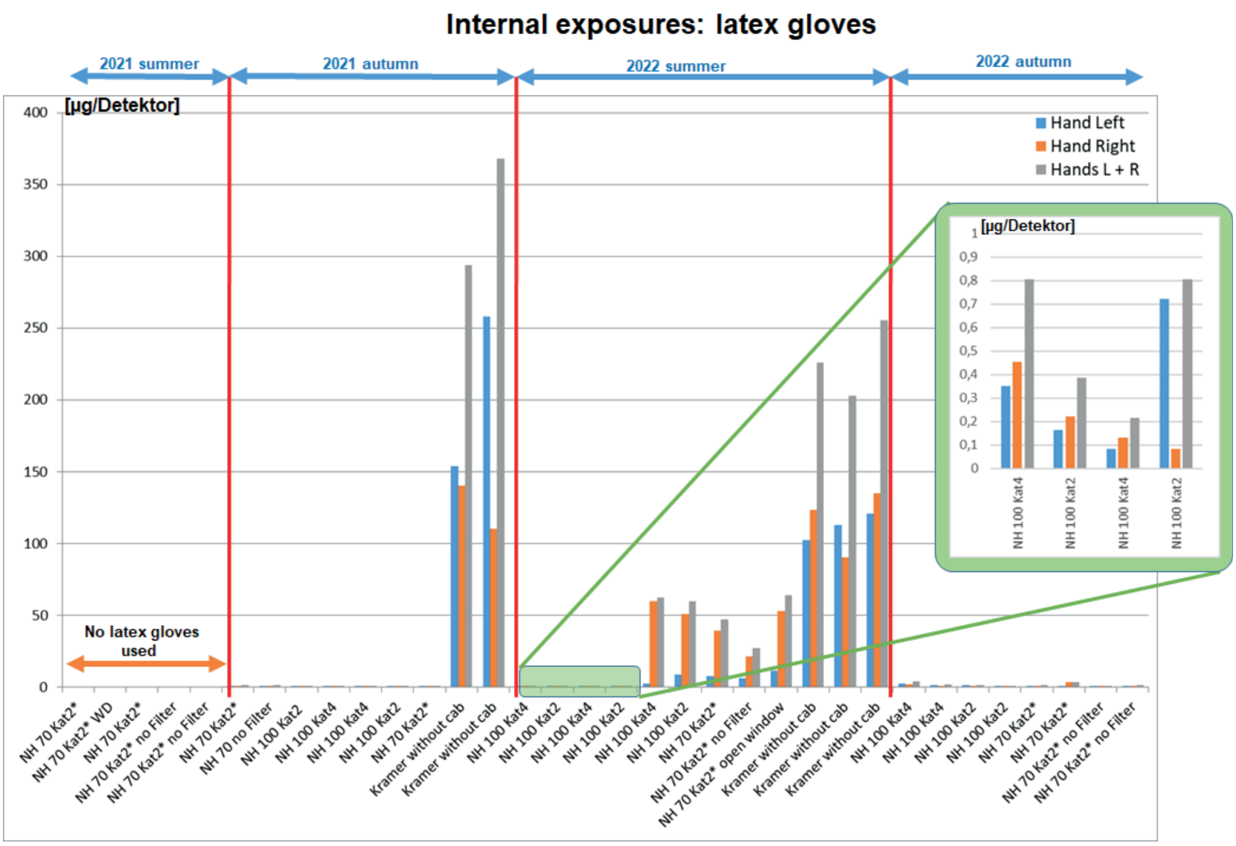

Fig. 10. The dermal exposure on the hand measured by using latex gloves in different scenarios

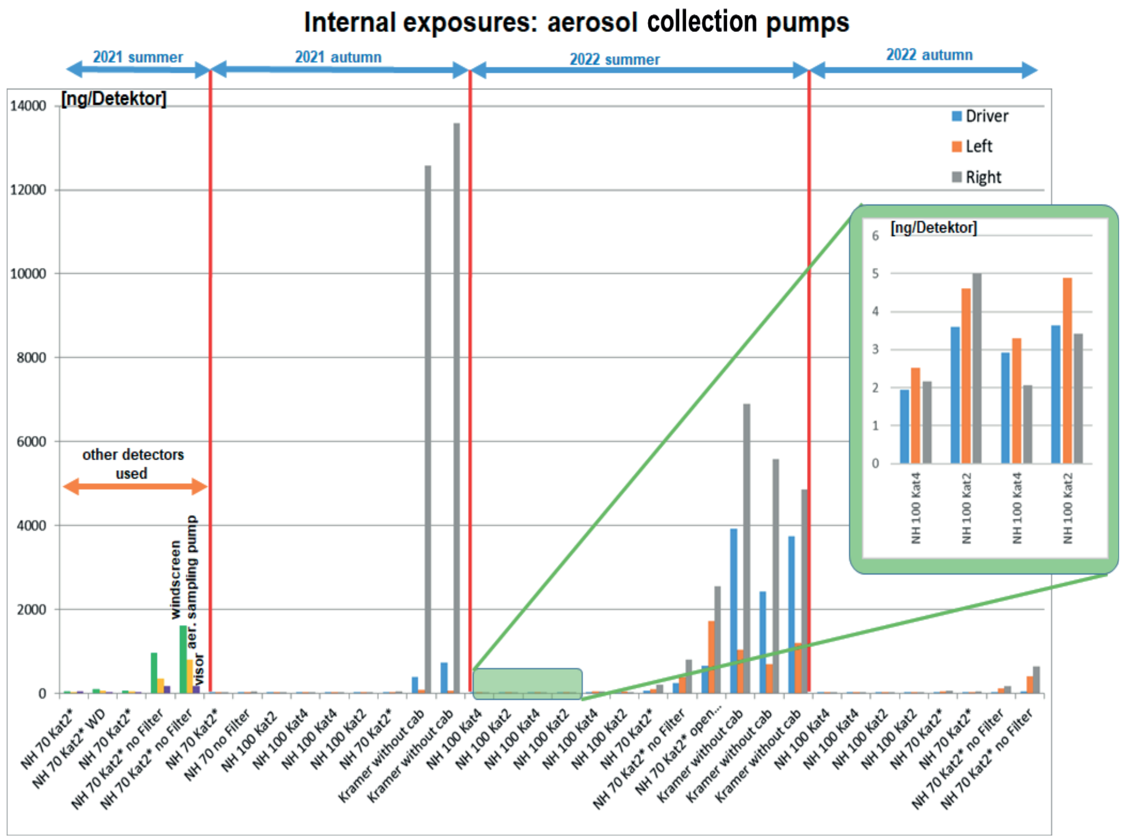

Fig. 11. Measured values for the inhalation exposure by using aerosol collection pumps

Katrin Ahrens[1], Markus Röver[2], Enrico Peter[3], Gabor Molnar[1], Sabine Martin[3], Jens Karl Wegener[1]

Development of a method for measuring exposure of residents and bystanders following high crop application of plant protection products

Entwicklung einer Methode zur Messung der Exposition von Anwohner und Nebenstehenden durch die Ausbringung von Pflanzenschutzmitteln in Raumkulturen

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Abstract

Residents and bystanders may be exposed to spray drift during application of plant protection products. The assessment of possible risks is carried out on the basis of a harmonized exposure model of EFSA. For orchards and vineyards, there are currently still gaps in the assessment. These data gaps have been addressed by BVL, JKI and BfR in a joint project. The development of a robust method to perform reproducible field trials was a core element of the project. The fluorescent dye pyranine served in the trials as a readily detectable substitute for real plant protection products. In the course of several years of optimization, suitable clothing was identified for mannequins representing adults and children. Tyvek® coveralls proved suitable for detecting even small amounts of dye with high accuracy. The development process provides the basis for a JKI guideline for preparing and conducting field trials. The different development stages are described here. The data generated with the developed method will enable EFSA to improve the exposure assessment models.

Keywords

exposure, drift measurement, residents, bystander, risk assessment, drift reduction

Zusammenfassung

Anwohner und Nebenstehende können bei der Ausbringung von Pflanzenschutzmitteln Spritznebeln ausgesetzt sein. Die Bewertung möglicher Risiken wird auf Basis eines harmonisierten Expositionsmodells der EFSA durchgeführt. Für Obst- und Weinbau bestehen aktuell noch Bewertungslücken. Diese Datenlücken wurden von BVL, JKI und BfR in einem Gemeinschaftsprojekt adressiert. Die Entwicklung einer robusten Methode zur Durchführung reproduzierbarer Feldversuche stellte ein Kernelement des Projektes dar. Der fluoreszierende Farbstoff Pyranin diente in den Versuchen als gut nachweisbarer Ersatz für echte Pflanzenschutzmittel. Im Zuge mehrjähriger Optimierungen wurde eine geeignete Bekleidung für Schaufensterpuppen gefunden, die Erwachsene und Kinder repräsentieren. Tyvek®-Overalls erwiesen sich als geeignet, um mit hoher Genauigkeit auch geringe Mengen an Farbstoff nachweisen zu können. Der Entwicklungsprozess liefert die Basis für eine JKI Richtlinie für die Vorbereitung und Durchführung von Feldversuchen. Die verschiedenen Entwicklungsstufen werden hier beschrieben. Die mit der entwickelten Methode ermittelten Daten ermöglichen der EFSA, die Modelle zur Expositionsbewertung zu verbessern.

Stichwörter

Raumkultur, Abdriftmessung, Anwohner, Nebenstehende, Bystander, Risikobewertung, Abdriftminderung

Introduction

Drift during the application of pesticides does not only affect the environment. Uninvolved persons such as bystanders (walkers, sportsmen, etc.) or residents can also be exposed unintendedly to spray drift, which might result in a potential health risk. Since 2016, the risk assessment for plant protection products of exposure for operators, workers, residents and bystanders has been carried out according to the internationally harmonised EFSA model (EFSA, 2014). Due to the lack of appropriate exposure study data, the collection of experimental data on spray drift exposure in high crops was strongly recommended in 2014. This request to provide new data was repeated in the revised guideline, which was published recently (EFSA et al., 2022).

For arable crops, many data have already been collected and models have been created. Matthews & Hamey (2003) find

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that bystander exposure is related to the proportion of droplets in a spray that remain in the air. Glass (2006) presented a method to measure bystander exposure. The data collected have been published, compared (Glass et al., 2010, Butler Ellis et al., 2010) and led to an exposure assessment model BREAM (Kennedy et al., 2012).

The exposure model for viticulture and orchards is based on rather old data from the 1980s (Lloyd et al., 1987). Exposure data for different distances from the treatment area and mitigation of exposure applying drift-reducing technology were not considered in the data set by Lloyd et al. (1987). Furthermore, the data available did not cover unintended exposure of children and therefore data were extrapolated from adult values.

To address some of the gaps identified the European Crop Protection Association (ECPA now CropLife Europe) started a project in 2015 to measure spray exposure for distances of 5 m, 10 m, and 15 m when applying pesticides in viticulture and orchards (HSE et al., 2021). Until recently, this data has not been made available for the models commonly used in risk assessment for the application of plant protection products.

Since 2016, the BVL has also been funding field studies conducted by the JKI – Institute for Application Techniques in Plant Protection as a project partner. On the one hand, it appeared necessary to obtain new data, which can later be used in regulatory decisions, in an independent way under the leadership of German authorities. On the other hand, it was concluded that all data sets known so far had gaps, i.e. data to support options for refinements in risk assessment were lacking. This includes the lack of data for drift mitigation measures (i.e. effects of different buffer sizes and drift-reducing technology). By closing these gaps, it is expected that a larger portfolio of risk mitigation measures can be used in the future when assessing the safe use of pesticides. Therefore, the project was regarded as part of the governmental tasks in the context of risk management in the approval process for plant protection products. Moreover, the project is economically independent and without the contribution of any industry partners or grants.

The following project parameters were identified during the design of the field studies:

- collect drift data with and without drift reducing technology (75%),
- include distances of 3 m, 5 m and 10 m,
- include application in early and late stages of culture growth (with low and high density of leaf wall)
- consider trials in orchards as well as in vineyards.
- take care of a sufficiently high predictive power and robustness based on data from many experiments. This will result in more reliable exposure estimates that are closer to reality and facilitate model development and acceptance.

The main goal of the presented work was to establish a simple and reproducible procedure to measure dermal and inhalation exposure of bystanders without using plant protection products. The central focus of the project so far has been on orchards. Extensive studies in vineyards have not yet been carried out.

General test setup for drift measurements in orchards

The experiments in orchards were carried out following JKI guideline 7-1.5 for drift measurements (JKI, 2013). In many areas the JKI guideline is identical to the ISO 22866:2005 (ISO, 2005) standard, but in regard to weather conditions stricter. The experimental setup of the experiments consists of a treatment and a measurement area, which must be located in the downwind direction next to the treatment area. The treated plot must be at least 50 m in length and 20 m in width. The row spacing of the crop determines the number of rows that have to be treated.

Applications in orchards are usually carried out with air assisted sprayers. Depending on the drift reduction setting, it may be necessary to block the air support on one side or also to reduce the fan speed (see Fig. 1 as example) for the treatment of the first rows. The number of rows treated in this way depends on the intended drift reduction class and sprayer specific parameters from the directory of loss-reducing equipment from JKI (2023). In the setting without drift reduction, all spraying was conducted with air-assistance.

The entire treatment area was sprayed with a test liquid. It contained water and a tracer substance, i.e. Pyranin 120% (Herbst & Wygoda, 2006), as a water-soluble, fluorescent dye for laboratory analysis. According to the experimental goal and the analytical methodology, the concentration of the dye in the spray liquid depends on the application parameters and the expected amount of the dye on the respective dosimeters.

The applications in all field trials in this project were carried out with a KA32/1000 orchard sprayer from Wanner (axial sprayer with attachment). The tractor speed was between 6.5 – 7 km/h, and the application rate was approximately 440 l/ha. The application pressure was adjusted depending on the nozzle type used in order to obtain similar application rates.

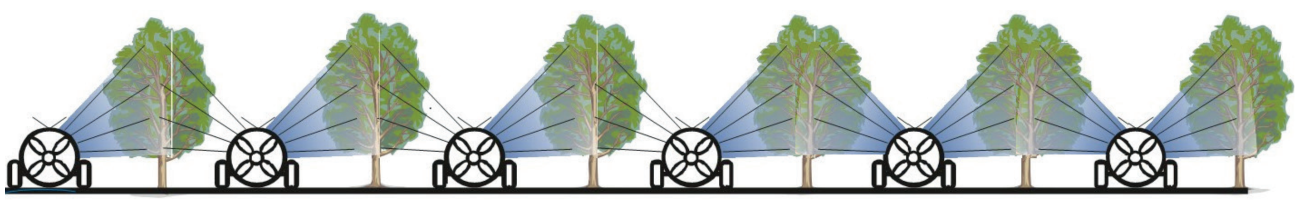

Fig. 1. Example of orchard spraying with drift reducing treatment. First row from left: fan and nozzles in direction to the field border are turned off; next three rows: nozzles on both sides are spraying, left side of blower is blocked, last two rows: both sides are sprayed air-assisted (lines from sprayer to trees symbolize spraying nozzles, blue areas stand for air-assisted spraying). © D. Rautmann

At least at the beginning and the end of a series of tests of each day, tank samples were taken in order to analyse the test liquid and confirm the dye concentration. Samples were taken either from the tank or collected directly at the nozzles using a scooping aid.

During the trials the following weather data were recorded every second:

- wind direction
- wind speed
- air temperature
- relative humidity

The collection of weather data followed the JKI guideline 7-1.5.

Outside the measuring area, spiked samples of all dosimeter materials used were laid out to determine field recovery rates. A known amount of pyranine, corresponding to the lowest and highest expected amount of the dye that would be detected in the subsequent laboratory measurements, was pipetted onto the dosimeters. Field recovery was measured in at least three replicates per dosimeter and dye concentration. In addition, at least three petri dishes with material samples without pyranine contamination were laid out for determination of blank values, too. The samples were placed in such a way that they could not be contaminated by spray drift from the current application, but were exposed to the same environmental conditions during the trials.

Initial considerations for drift collectors

In order to be able to measure and assess the exposure of residents and bystanders towards spray drift, mannequins were placed on the measurement area. At the beginning of the project, the mannequins should be dressed with long underwear, T-shirt, shorts and headgear. The underwear was intended to simulate naked skin and as such to serve as an inner dosimeter for actual dermal exposure. The outer garments should simulate the protective effect of shorts and T-shirt. The sum of the amounts of dye detected on underwear and outer garments corresponds to the potential dermal exposure of a resident or bystander.

Following a project at JKI evaluating operator exposure when using "Close Transfer Systems (CTS)" (Kemmerling et al., 2018), an analytical procedure was developed to check the suitability of the materials and to determine the recovery rates of pyranine ("Pyranin 120%") under defined conditions.

According to this analysis procedure, the clothing used in the present project was prewashed several times in a washing machine (Miele, W1 classic, type WDB030 WCS Eco) using the "Express 20" washing program without the addition of detergents. Any water-soluble residues being present, such as dyes and bleaching agents, should thus be extracted. These residues were minimized by multiple washing cycles in order to obtain constant and low blank values. The clothing was washed individually at 30 °C for 20 minutes, and the wash water was collected in a large container outside the washing machine. From each washing cycle, the wash water was weighed – about 17 kg for the program used – and wash water samples were taken with a rolled rim glass for analysis. The analysis was performed on a fluorimeter (SFM25, Kontron Instruments). A number of 10 pre-washes were necessary to achieve a low blank value. Afterwards, recovery rates were determined based on spiked clothing samples.

As preliminary tests showed that normal tap water has an influence on the measurements of the blank values, a demineralization system VE-Station 100 Mono (AFT GmbH & Co KG., Roßtal, Germany) was installed in order to wash with demineralized water.

The selection of the underwear (e.g. cotton stretch Long Pants and Longsleeve, Engelbert Strauß GmbH & Co. KG., Biebergemünd, Germany), consisting of 95% cotton and 5% polyester, was based on the results from the CTS project (Fig. 2, left). It was decided that a shortened patient gown (Fig. 2, right) would be used instead of T-shirt and shorts. This was done to prevent cross-contamination between the different layers of clothing while undressing the mannequins and to allow a relatively quick change of clothing in the field. In terms of sustainability, it was planned to reuse all the garments for the trials.

For the choice of an appropriate headgear, two different balaclavas consisting of 95% cotton + 5% elastane and 100% cotton were compared in a preliminary test. The balaclavas were first prewashed ten times and dye concentrations in the wash solution were determined. In order to identify the most efficient method for washing, two methods were compared with each other. The balaclavas were either washed with the washing machine or in a PE container using a defined amount of water to extract the dye under gentle agitation on a shaker. Washing in the washing machine was carried out with the same washing program as for gowns and underwear. In the laboratory, however, PE containers with a capacity of 2000 ml were used and different amounts of water (300 ml, 400 ml and 600 ml) were tested. Prior to analysis, the filled containers were placed on a laboratory shaker at 75 rpm for a total of 20 minutes. After 10 minutes, each container was rotated 180° to wet and rinse the balaclava completely. The results showed that the washing machine was unsuitable for one balaclava due to large amounts of water and low fabric content. In the laboratory analyses, best results were obtained for balaclavas made of 100% cotton and a washing volume of 400 ml of demineralized water.

Ground sediments were determined in parallel to the measurement of exposure of residents and bystanders. Since ground deposits are used to assign drift reduction classes (Ganzelmeier et al., 1995; Rautmann, 2001), the data on ground deposits were considered as intrinsic control to ensure that the anticipated drift reduction level was achieved in the experiment. Ground deposits were measured using petri dishes with a diameter of 14.5 cm as standard dosimeters (c.f. JKI-guideline 7-1.5). Laboratory analysis was performed by adding 40 ml of demineralized water to the petri dishes. The petri dishes were placed on a shaker for 10 minutes at 55 rpm to dissolve the dried pyranine. Afterwards, the solution was analysed using a fluorimeter.

In addition, pre-tests were carried out in order to explore options to simplify the 3D measurements. Aluminium frames (2 m × 1 m in height and width, respectively) were constructed (see Fig. 4, left). Thin lines made of polyethylene (PE) with a diameter of about 2 mm were fixed at a defined distance

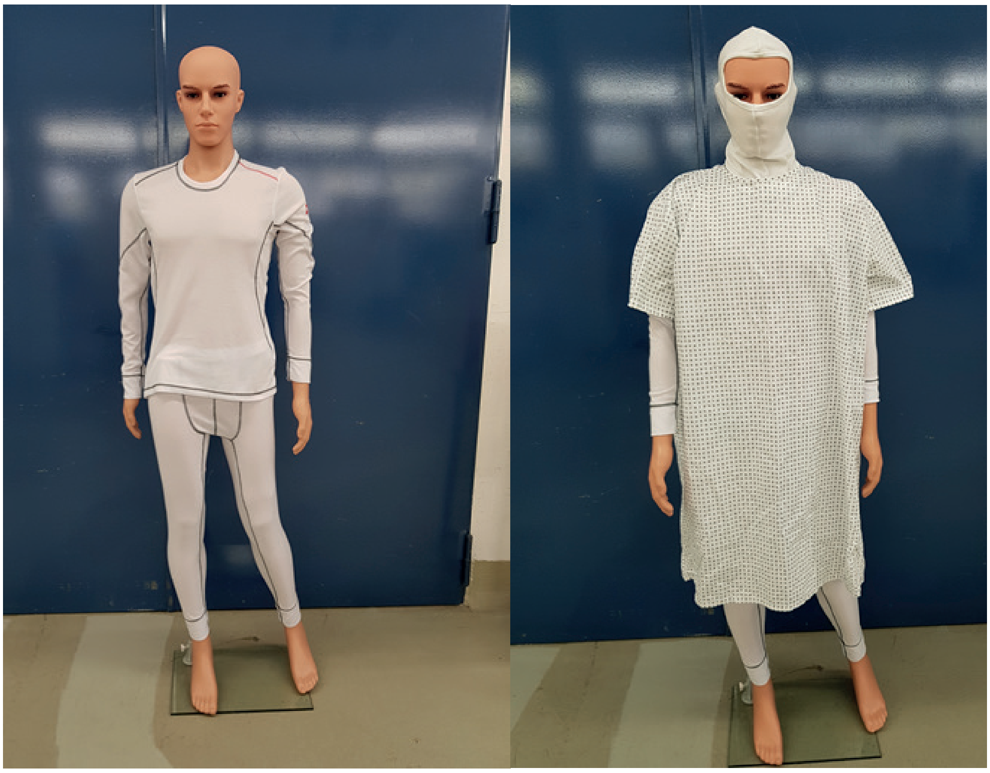

Fig. 2. Mannequin dressed in underwear (left); mannequin dressed in outer clothing and underwear (gown before shortening) and balaclava as headgear (right).

(10 cm or 20 cm) to record air concentration. Such frames with strings were were already used earlier to study spray mist, especially in wind tunnel measurements (Herbst & Molnar, 2002). In the field, after spraying, the strings were individually bagged and stored in the dark. In the laboratory, 20 ml of demineralized water was added to the bags to re-dissolve the pyranine under gentle agitation. The obtained solutions were analysed fluorometrically.

Inhalation exposure was measured with a collection head, which is connected to an aerosol collection pump via a PE hose. An IOM sampler (SKC Limited, Dorset, Great Britain) was selected as the collection head. The samplers were attached to the mannequins at neck level in the breathing zone. The flow rate was set to 2 l/min per minute. Measured values were converted to the respiration rate of an adult or child (EFSA, 2014)) during data analysis.

For the collection head, the company Sartorius (Sartorius AG, Göttingen, Germany) recommended different fibreglass filters, which were tested in a preliminary trial under laboratory conditions. These filters are made of 100% borosilicate glass. High recovery rates showed that all fibreglass filters are suitable for the described application and thus for the quantitative detection of pyranine. For laboratory analysis, the filters were placed in a rolled rim glass. A defined amount of demineralized water was added. The pyranine was dissolved in an ultrasonic bath and the solution was finally analysed using a fluorimeter.

First test trials in the field

First test trials took place in March 2019 (with the test set-up shown in Fig. 3) in the open field on the JKI test site at Messeweg in Braunschweig with a Wanner KA32/1000 (see Fig. 4, right) with CVI 80-01 flat fan nozzles. The nozzle pressure was 10.0 bar. Two runs with six passes each were performed. On the first pass, the nozzles and fan were switched off in the direction of the measuring field, and on the second to sixth pass, the nozzles and fan were switched on on both sides. As drift samplers for each run, two clothed adult mannequins, each with aerosol collection pumps and two frames, each with 10 strings (20 cm spacing), were placed at distances of 3 m and 10 m. In total 63 petri dishes were also distributed 3 m (20), 5 m (23), and 10 m (20) away from the zero-line.

Overall, it became evident that the trials were very personnel-intensive. The handling of the clothes was cumbersome and time-consuming. Two gowns touched the ground while undressing the mannequins and could not be used in evaluation. In the field, the mannequins had to be protected against falling over.

The wash solutions were analysed with a fluorimeter from Kontron. Table 1 shows the limit of detection (LOD) and the limit of quantitation (LOQ) derived from the calibration series and the blank values for the body dosimeters, which were determined based on the pre-washes are shown. In comparison, the values for the underwear are very high. This could be explained by the need to switch to a different measuring range, which led to higher LOD and LOQ with lower sensitivity. Therefore, all values for the underwear were below the LOQ. The blank values for the filters, petri dishes and collector lines were below the LOD.

The analysis was complex, since the measured values covered several orders of magnitude. For this reason the sensitivity of the fluorimeter had to be changed frequently, which limited the measuring range. The values were often too high for the respective fluorimeter setting, while others were already below the LOQ.

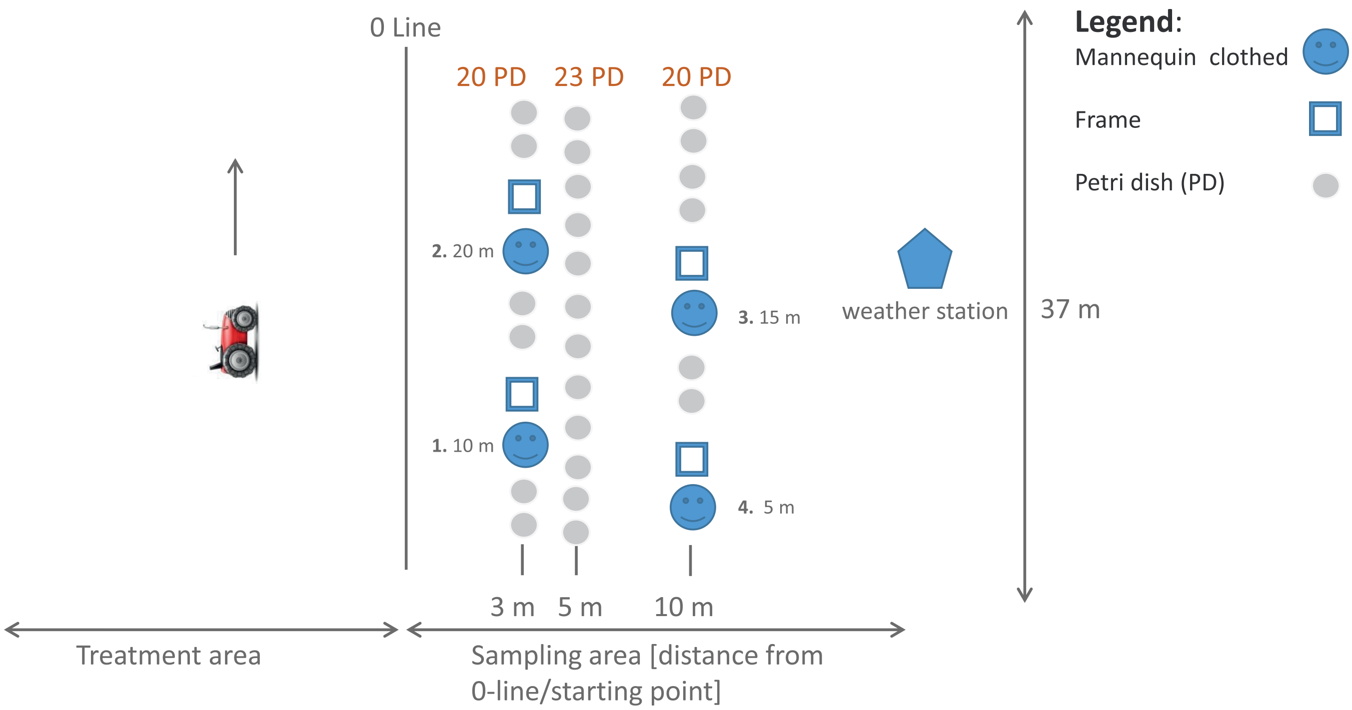

Fig. 3. Test setup for the first field trials following JKI Guideline 7-1.5 for drift measurements.

Fig. 4. Arrangement of the dosimeters on the measuring area (left) and the orchard sprayer (KA32/1000 from Wanner) used (right).

For this reason, a new SF 6000 fluorimeter from Shimadzu, was used. With this instrument, the excitation wavelength can be adjusted easily, and the sensitivity is better. The new device works with electronic data acquisition and calculates an average value from three measured values. This led to more robust data. Parallel to the implementation of the new fluorimeter, calibration procedures according to DIN 32645 (DIN, 2008) and DIN 38402 (DIN, 2017) were established in the analytical unit.

In order to improve the experimental set-up, further preliminary trials took place in August 2019 (with the test setup shown in Fig. 5). Experiments were conducted with a Wanner KA32/1000 with Lechler IDK 90-015 nozzles in the orchard at the JKI location Braunschweig-Bundesallee. The spray pressure was 8 bar. In the first row, the nozzles and blower directing to the measuring area were switched off. In the 2nd and 3rd rows, the blower directing to the measuring area was made ineffec-

Table 1. LOD, LOQ and blank values for the dosimeter used in the first test trials.

	LOD [µg/Dosimeter]	LOQ [µg/Dosimeter]	Blank value [µg/Dosimeter]	Dilution volume [ml]	Surface [cm²]
Balaclava	6.2	18.4	0.12	400	1240
Gown	8.2	26.1	11.0	~ 17,000	
Underwear	241.2	712.3	26.6	~ 17,000	15460
Filter aerosol collecting pump	0.5	1.4	-	40	3.1
Petri dish	0.6	1.6	-	40	165
Collector lines	2.1	6.1	-	20	62.8

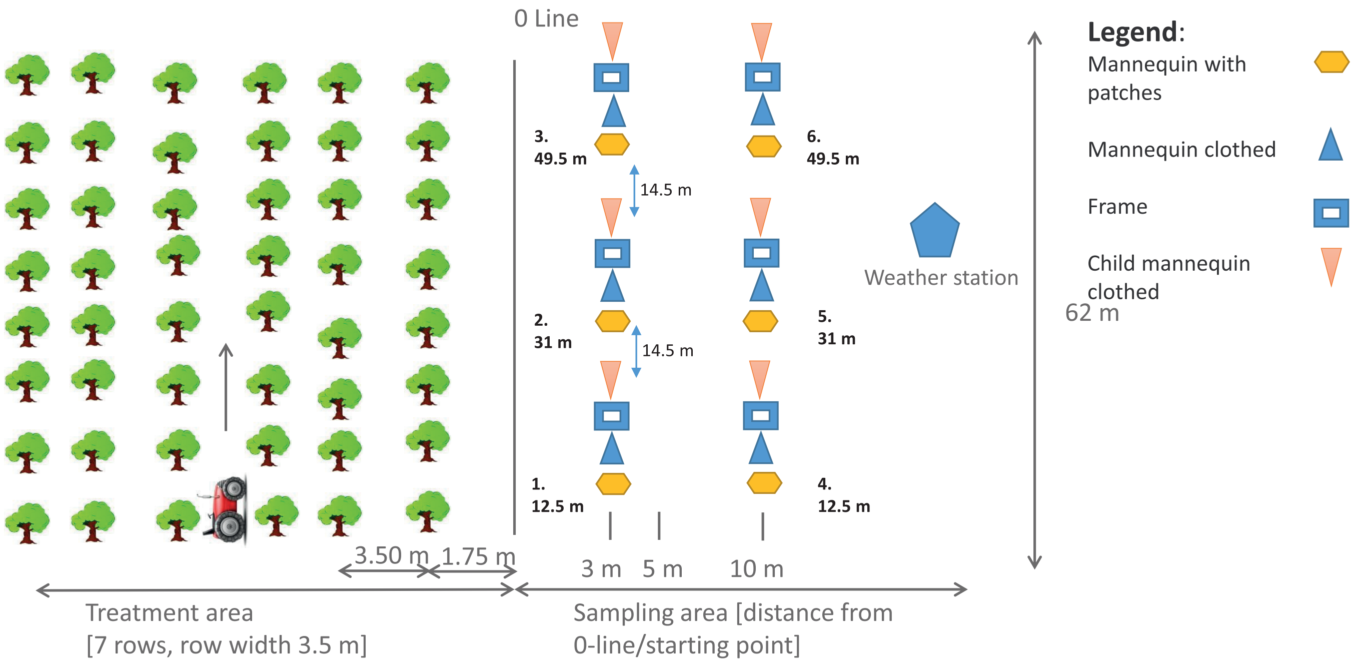

Fig. 5. Test setup for the second field trials following JKI Guideline 7-1.5 for drift measurements.

tive, in the 4th – 7th rows, on both sides the nozzles and blower were on. This represents a setting of 75% drift reduction.

The trial was extended – compared to the planned working program: In addition to the aluminium frames with PE collector lines and the fully dressed mannequins two additional dosimeters were used: first, clothed child mannequins were set up on the field; second, mannequins clothed only with gowns were equipped with 34 filter paper patches with a diameter of 125 mm on each mannequin (Fig. 7). In the laboratory, the filter paper patches were analysed after the addition of 40 ml of demineralized water. The aim was to find possible correlations between the different dosimeters in simplify the experimental setup in the future. The distribution of the patches on the mannequins and clothing is shown in Figure 6. The PE strings were clamped into the aluminium frames every 10 cm to achieve higher spatial resolutions. This represents a doubling of samples compared to the first trial (every 20 cm).

The results of the dosimeter evaluation for balaclava, gown and underwear on adult and child mannequins showed that the amounts of the dye present on gown and underwear were again below LOQ for most samples (38 of 48). LOD, LOQ and blank samples are shown in Table 2. The values of the gown were above the LOQ only in the samples obtained

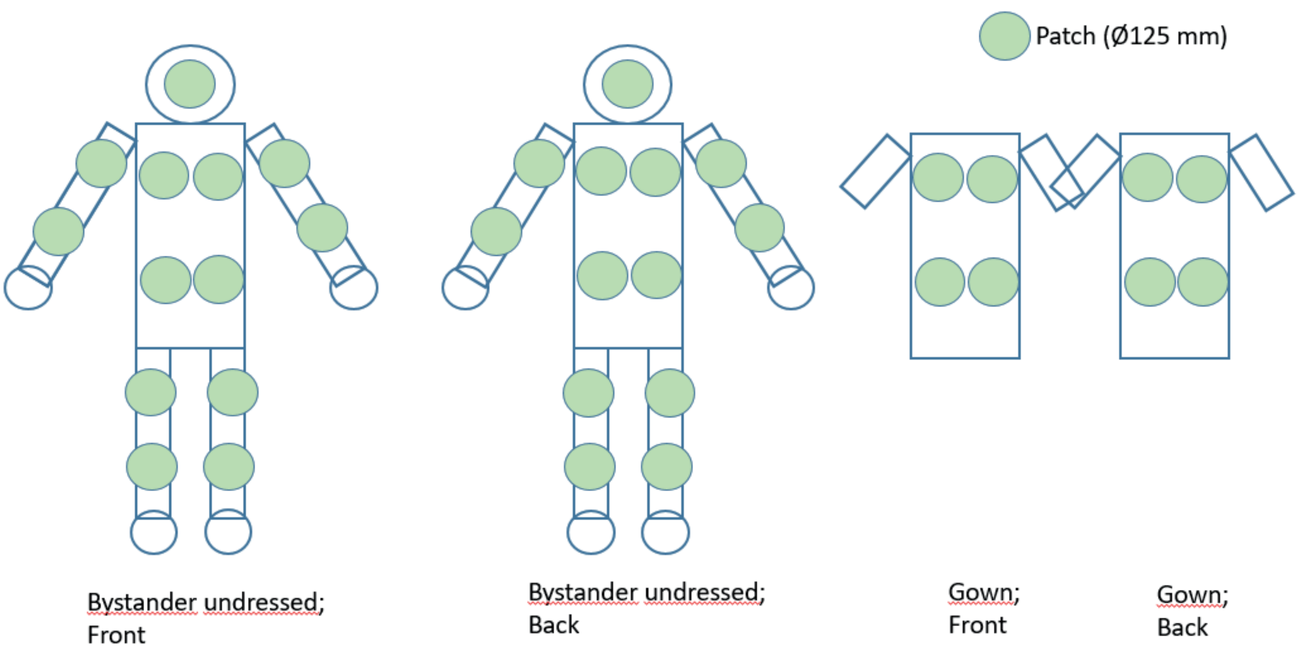

Fig. 6. Arrangement of filter paper patches on the front and back of the naked mannequins and on the gowns

Fig. 7. Example for the dosimeters used in the first trials (left) and the young orchard at the test site (right).

from adult mannequins at 3 m distance, but still below LOD at 10 m distance. Again, it turned out that the methodology is not sensitive enough resulting in a high number of values below LOQ.

Figure 8 shows the data of the evaluations of the filter paper patches for adult mannequins for the two experimental runs in numbers and by colours in qualitative terms. The values of almost all patches under the gowns were below LOD. These filter paper patches were intended to simulate dermal exposure underneath the clothing. This approach was given up due to the small values.

The evaluation of the other 26 filter paper patches per mannequin revealed plausible results. The total exposure of the mannequins at 3 m distance is higher on the front side as well as on the back side as opposed to the mannequins at 10 m distance. Furthermore, the total exposure per mannequin is higher on the front side compared to the backside. Additionally, the maximum exposure occurs mainly on the patches on the head. This is consistent with the results of the analysis of the strings (c.f. Fig. 9). For most of the mannequins, all patches yielded measured values above the LOQ. The range of variation in the total exposure shows a factor of about 2-4. This second test trial confirmed the results of the first test run, so that reproducibility under field conditions in general could be assumed.

Figure 9 shows the exposure values on the strings clamped at 10 cm intervals in frames at a height of 10 cm to 200 cm above the ground. The measurement results of all strings were above the LOD and LOQ. Saturation effects or dripping from the cords were not recognised. In the test repetition, one measured value is missing (Fig. 9; 10 m), the reason being that the string fell down during the field test. This reproducibility was deemed sufficient for trials under field conditions.

The amount of dye detected at 3 m distance increased continuously from bottom to top. Again, the total exposure values per frame are subject to fluctuations when comparing the runs. At 10 meters, the total exposure varied by a factor of 2. Strikingly, the maximum amounts of the dye were found in different height ranges. However, similar to the pattern observed at a distance of 3 m, there is also a tendency for increasing values from bottom to top, but this is not as stringent. Nevertheless, this is consistent with the results of the analysis of the patches.

The values from the strings were also considered as plausible. They clearly show that the total exposure is higher at 3 m distance than at 10 m. Obviously this could be explained by the spraying device used (axial fan with fan attachment), since it blows the air laterally, obliquely upwards, and spraying into the air takes place even when the fan is switched off. Further, the larger drops settle quickly on the first meters while the smaller ones travel larger distances. This effect is particularly noticeable at a distance of 3 m, but it decreases with increasing distance. This is because the kinetic energy of the droplets in the drift cloud induced by the machine loses more and more of its effect. Here, environmental factors (wind) play an increasing role in influencing the movement of spray droplets.

Table 2. LOD, LOQ and blank values for the dosimeter used in the second test trials.

	LOD [µg/Dosimeter]	LOQ [µg/Dosimeter]	Blank value [µg/Dosimeter]	Dilution volume [ml]	Surface [cm²]
Balaclava adult	6.3	18.6	0.2	400	1240
Gown adult	167.9	502.0	9.8	~ 17,000	
Underwear adult	358.0	1,039.3	18.5	~ 17,000	15460
Balaclava child	5.6	16.8	0.2	400	860
Gown child	344.3	1,000.6	0.8	~ 17,000	
Underwear child	381.8	1,108.9	0.7	~ 17,000	6108
Filter aerosol collecting pump	0.05	0.14	-	40	3.1
Collector lines	0.1	0.4	-	20	62.8
Filter paper patch	0.1	0.2	-	40	122.7

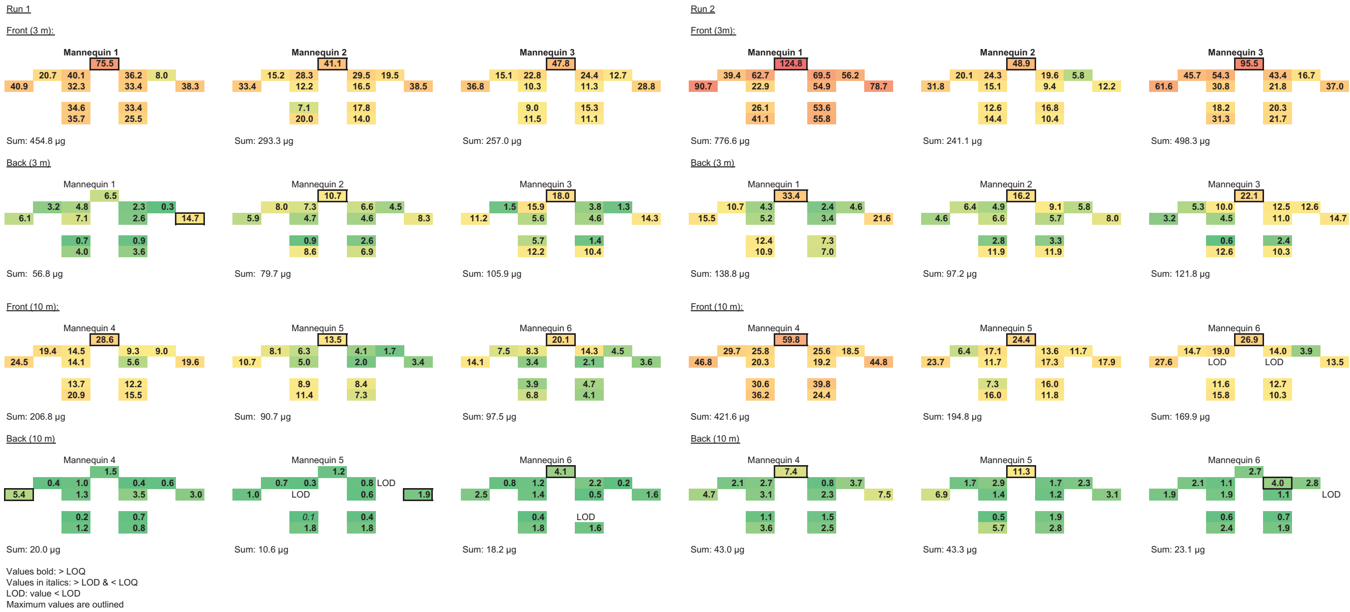

Fig. 8. Exposure values of the patches at a distance of 3 m and 10 m from the treatment area. The values (µg/patch) show the results for the patches from different parts of the body (1st and 3rd line = front, 2nd and 4th line = back) of the mannequins for different distances (3 m and 10 m). Also presented is the total exposure per mannequin front or back. Bold are all values above the limit of quantification, italics between LOD and LOQ, values below the LOD are marked with "LOD". Maximum values are outlined. In qualitative terms, the different colours indicate the exposure level per patch from green (low exposure) to red (high exposure).

In summary, the results of the second test trial showed that LOD and LOQ were still too high for the clothing items washed out in the washing machine and for the aerosol collection pumps (c.f. Table 2). The results obtained from the patches and the strings seemed plausible, as the detected amounts of the dye decreased with increasing distance to the treatment area. However, no robust dermal exposure of a resident or bystander could be derived from the data obtained from these two drift collectors.

To overcome the LOD/LOQ problem with clothing wind tunnel tests were carried out. The relationship of exposition between bodies, cylinders, and strings should be investigated. Different drift collectors were tested. These collectors were about the size of a (child's) mannequin. On the one hand,

	Run 1						Run 2					
	Distance 3 m:			Distance 10 m:			Distance 3 m:			Distance 10 m:		
Hight [cm]	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5	Frame 6	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5	Frame 6
200	27.2	41.5	51.1	10.1	18.0	13.7	56.1	41.1	44.9	33.2	17.9	21.6
190	28.1	39.7	50.9	9.8	18.6	14.7	56.7	41.5	50.5	32.9	17.1	22.0
180	30.9	38.3	49.4	10.2	19.6	15.0	56.3	44.2	51.8	33.2	17.2	20.5
170	27.6	37.8	48.5	10.0	20.1	14.9	56.8	45.2	54.8	31.0	16.3	21.8
160	26.7	37.8	45.4	9.4	20.9	15.2	55.2	39.0	51.7	34.3	16.8	20.7
150	26.2	39.0	43.3	10.0	21.3	14.9	56.0	41.6	52.7	33.3	18.1	20.9
140	27.1	37.9	42.4	9.6	21.6	14.3	56.3	46.2	51.7	33.0	16.6	20.0
130	30.1	38.2	41.7	9.3	20.5	14.0	58.3	43.3	51.7	35.2	16.2	19.6
120	29.1	36.3	40.5	9.5	20.1	13.5	39.3	42.7	49.9	29.7	16.4	18.1
110	28.2	35.6	41.9	8.9	18.6	13.2	52.3	43.4	48.7	35.5	15.6	15.2
100	29.1	34.2	39.5	8.7	18.2	12.4	53.9	42.3	45.2	35.2	15.0	missing
90	25.9	36.1	40.2	8.6	18.1	12.4	50.5	40.0	47.4	34.5	13.8	19.1
80	23.9	35.9	39.7	8.1	18.1	16.7	48.7	38.5	39.5	34.7	14.5	18.6
70	24.6	36.7	37.8	7.9	18.7	11.5	51.1	38.9	43.8	34.1	14.0	17.7
60	21.1	35.3	37.6	7.4	18.4	11.4	48.5	36.9	40.8	30.5	13.5	17.4
50	22.4	29.9	35.3	7.3	18.4	10.9	33.9	33.2	37.9	29.9	11.2	16.4
40	21.7	27.1	35.5	7.4	18.0	11.0	44.6	34.3	29.2	30.2	12.8	15.9
30	23.2	19.5	33.0	6.7	17.2	10.5	42.7	33.5	32.5	24.3	11.6	14.8
20	18.7	8.9	33.0	5.9	17.1	9.6	41.5	29.8	28.3	26.0	9.8	12.5
10	15.2	5.9	26.9	4.4	12.1	5.6	30.2	19.5	22.4	17.1	7.0	7.4
Total exposure [µg] per frame:	**507.1**	**651.5**	**813.7**	**169.2**	**373.7**	**255.2**	**989.0**	**775.0**	**875.4**	**627.9**	**291.7**	**340.2**

Fig. 9. Exposure values on the PE lines from 10 cm to 200 cm height (spaced: 10 cm) at a distance of 3 m and 10 m from the treatment area in both experiments. Maximum values are outlined. Exposure levels are colour-coded from green (low exposure) to red (high exposure). The values are shown in µg/line. The values were also summed up for each frame. The colour values give a qualitative impression of the exposure level from green (low exposure) to red (high exposure). Maximum values are outlined.

it was to be tested whether the collectors have comparable exposure and deliver comparable results. Secondly, the handling of these dosimeters was to be evaluated. Mannequins are cumbersome to dress and undress on the field, so alternatives were sought. A child's mannequin dressed in a gown served as a reference. The cross-section of the wind tunnel only allows the installation of a child mannequin. The collectors examined were cylindrical bodies the size of a child's torso. The cylindrical body was covered either with a plastic bag or with filter paper patches. In addition, an aluminium frame with five strings was used in the height range of the child's torso. Contrary to expectations, the measured values for dermal exposure of 3D bodies proved hardly reproducible in the wind tunnel. The turbulent flow around the bodies was assumed to be the main reason. It is also difficult to create a drift cloud in the wind tunnel. Due to these findings, the idea of alternative collectors replacing the mannequins in the field was dismissed.

Final Set Up for field trials

In an approach to overcome the described issues for extraction and quantification, the different types of clothing of the mannequins were replaced by Tyvek® coveralls (Xpert 500, Fa. Dupont) in 2021. Coveralls made of this material were also used in field trials with bystanders in arable crops (Glass et al., 2010). Laboratory tests with the Tyvek® material showed high recovery rates of over 95%, indicating that the removal of the dye from the material was simple and efficient. Based on the above results, it was decided that only the potential exposure would be determined in the subsequent trials. A reduction in the actual exposure of the respective body areas due to T-shirts and shorts can be taken into account by calculation afterwards.

To reduce effort during trials on the field, coveralls were prepared beforehand. The arms were cut off, the legs were split open. To fit a size S adult coverall to children's size, the legs were cut off and the torso was made narrower.

In detail, the coveralls for the mannequins were prepared as follows (see Fig. 10 for prepared coveralls):

Adults (coverall size L):

- Cut arms to T-shirt length, place double-sided tape (inside) on upper end.
- Mark cutting line for shorts (44 cm below horizontal seam at upper body).
- Cut legs open at crotch (cut entire seam inside legs) and fasten/pin up with safety pins to avoid ground contact when dressing mannequins in a contaminated experimental area.

Children (coverall size S):

- Cut arms to T-shirt length, trim to 33 cm length, place double-sided tape at the upper end of the pieces (inside).
- Cut legs at 54 cm.
- Mark cutting line for shorts (11 cm below horizontal seam at upper body).
- Weld/sew torso smaller

To avoid cross-contamination, 5 L garbage bags were pulled over the heads of the mannequins at each run, gloves and booties were put on. These were removed and discarded after every run. The gloves were removed first, then the Tyvek®-coverall was cut in pieces and the resulting parts were wrapped individually. Finally the booties and garbage bag were removed.

For laboratory analysis, the single Tyvek® pieces were washed out in their bags with 1.5 L of demineralized water. The sample was shaken and kneaded well by hand for about 2 minutes. Subsequently, the material was left to rest for 10 min to

Fig. 10. Prepared coveralls with material to be put on the mannequins

get soaked for 10 minutes. The samples were shaken again, before the solution was analysed fluorometrically.

For inhalation exposure, the sampler unit of the aerosol collection pumps was optimized on the intake side. The IOM samplers originally used were not suitable for changing filters on the field without the risk of cross-contamination. In addition, a very fine-pored nitrocellulose filter with an increased effective collector area was used. Material tests showed that the nitrocellulose material has acceptable characteristics in terms of intrinsic contamination (blank value) and recovery rate under laboratory conditions. The pore size of the filter is 0.22 µm, which retains even the smallest aerosol particles. The enlarged detector area allows for greater spatial perception, and it causes only a small resistance to air flow. All factors mentioned above influence the measurement essentially. The nitrocellulose filters were replaced by fibreglass filters following the first field trials, as the nitrocellulose filters showed enormous degradation under environmental conditions, as indicated by the poor field recovery.

The final experimental setup is shown in Figure 11. Nine pairs of adult and child mannequins were placed at distances of 3 m, 5 m and 10 m from the zero line. They were firmly anchored in the ground (e.g. with square tubes) in order to stand securely even in strong winds. The zero line for determining distances from the trial area in tree fruit, vine and hop production is half a row distance from the outermost row.

Within each pair of mannequins there was a distance of 1.50 m between the anchors. In order to prevent "wind shading", mannequin pairs should be separated by at least 10 meters. For this reason, each row has a lateral offset. In the presented setup it was taken into account that the wind could deviate up to 30° from the main wind direction.

In order to collect samples to measure ground deposits, five petri dishes were placed one meter apart from each other between each pair of mannequins (10 replicates per distance, 30 in total). Only 15 aerosol collecting pumps were available and regarded as sufficient for data collection. They were distributed evenly across the sampling area. The samplers were positioned at neck height in the breathing zone of an adult or child (c.f. Fig. 12).

The weather conditions (temperature, humidity, wind speed and wind direction) were recorded every second with a meteorological station (Fa. Lambrecht WENTO-IND) with cup anemometer and wind direction sensor placed in the middle of the field downwind behind the sampling area.

Before each run, the mannequins were dressed starting at 3 meters.

Adults: put on garbage bag, gloves, booties, coverall from the top (for this the seam has been cut open at the crotch) – with zipper to the back; loosen safety pins and wrap legs and fix fabric with clamps at the crotch, fasten arms ensuring that the hands of the mannequins are covered as completely as possible (to the base joints of the fingers).

Children: put on garbage bag, gloves/bag, booties, suit – with zipper to the back; wrap legs tightly and fix fabric with a clamp in the back, fasten arms ensuring that hands of the mannequins are covered as completely as possible (to the base joints of the fingers).

Approximately five minutes after each run (when spray had settled completely), collection of the dosimeters (beginning at 10 meters) started. Using scissors, the coveralls were cut along the pre-defined cutting lines into pieces (two arms, two legs, head and torso), folded carefully with the outside facing outward and packed into separate labelled plastic bags for

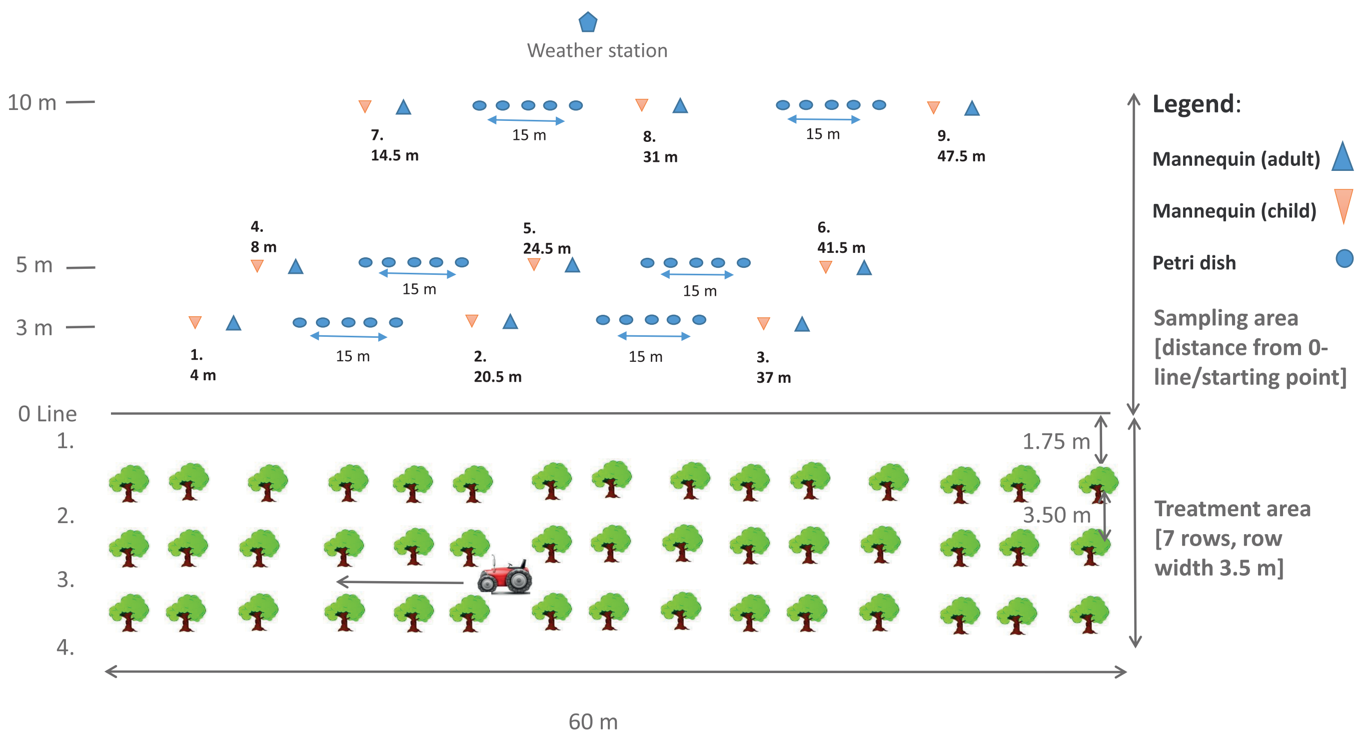

Fig. 11. Final setup for the field trials following JKI Guideline 7-1.5 for drift measurements.

Fig. 12. Mannequin pair (left); spraying in non-leavy orchard ("Orchard early stage"; right).

transport, storage and analysis (2 persons recommended for contamination free packing). The bags were loosely sealed with cable ties.

By cutting the Tyvek® coveralls into body and limbs, it is possible to calculate the actual exposure from the total exposure in the subsequent interpretation of the measurement results. For this purpose, the exposure of the torso is halved to account for the protective effect of shorts and t-shirt.

The filter elements of the aerosol collecting pumps were stored and replaced by new ones. Waste bags, gloves and plastic shoe covers were discarded and replaced by new ones. They have only been used to avoid cross contamination. All plastic bags with Tyvek® pieces, filter elements and petri dishes were stored in the dark immediately after the experiments. Samples were kept at ambient temperature. Care had to be taken to ensure that no material (scissors, garbage bags, freezer bags, suits etc.) touched the ground during the entire time period to prevent contamination by residues of the spray liquid. Laboratory analysis was performed in a timely manner. At least one day in the laboratory was required for the evaluation of the drift samplers for a single run. Due to the improvements of the dosimeters and the laboratory phase, the analytical problems with LOD and LOQ were overcome.

With drift collectors prepared as described, six test series of eight runs each were run between September 2021 and October 2022. The five trials took place in the orchard on the JKI-site in Braunschweig and one in the orchard center Esteborg in Jork. The trials were carried out with and without drift-reducing technology. In order to get at least ten measurements per type of mannequins and distance in a series, eight runs, i.e. four runs per sprayer setting (+/- drift reduction), were performed in randomized order in each of the eight series.

The results obtained with the final experimental design are very promising. The runs with drift-reducing settings of the sprayer showed that the anticipated drift reduction of 75% could also achieved when using three-dimensional drift collectors. As expected, exposure of the residents/bystanders decreased with increasing distance from the treatment area. The experimental data of the results with the final trial will soon be published and should be submitted to EFSA for evaluation in the framework of the next revision of the guidance on the assessment of non-dietary exposure.

Conclusion

A suitable experimental set-up for the reproducible measurement of potential exposure of residents or bystanders towards spray drift resulting from the application of plant protection products in orchards was developed. Apart from the need for sufficient statistical power, the selection of materials for dosimeters and well elaborated procedures for the extraction and analysis of the tracer were identified as crucial for successful experiments delivering high quality data. The usage of a dye as a tracer to determine exposure is – in contrast to the active ingredients of a plant protection product – harmless for the many people working with the dosimeters in the trials.

During the course of the experiments, the use of mannequins dressed in Tyvek® coveralls proved to be the most reliable setup to measure the potential dermal exposure. Additionally, aerosol collection heads with special filter carriers were developed and showed to be a good choice for measuring inhalation exposure. The approach described here will be the basis for a new guideline for 3D spray-drift measurement – similar to the JKI guideline 7.1-5.

In total 864 data points for potential dermal exposure were generated. The data set is considered as a valuable basis to further improve the models used in non-dietary risk assessment and also to implement new options for risk mitigation measures. Consequently, they will be submitted to EFSA for peer review.

During the course of the project, more intensive work was done on collecting data on the exposition of bystanders and residents. To name a few: in France, trials were undertaken in viticulture with a similar experimental set-up with nine adult and child mannequin pairs (Mercier, 2020). In another French collaborative project, a harmonised protocol was developed to conduct bystander trials in arable crops, orchards, and vineyards (Verpont et al., 2022). In Switzerland, trials with drones were performed in orchards (Dubuis et al., 2023). Here, the mannequins wore coveralls, and trials took place in early and late orchard foliage. Kuster et al. (2021) compared bystander trials in arable crops from 2012 – 2019 with the BREAM and BREAM2 (Butler Ellis et al., 2018). The latter model was further developed from wind tunnel trials. Further investigations in the wind tunnel dealt with the application volume at bystander exposures (Butler Ellis et al., 2022).

In the next years, a follow-up project based on the methodology as described here will investigate the drift-reducing potential for sprayer settings of 90% and 95% drift reduction. Furthermore, the impact of different water application rates on the exposure towards spray drift should be explored. Trials with drones are also on the agenda of the future project. In October 2022, preliminary 3D test trials were conducted with drones in a vineyard in southern Germany. These tests already followed a first draft of the new study-guideline on 3D drift measurements.

Conflicts of interest

The author(s) declare that they do not have any conflicts of interest.

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Spray drift from application of plant protection products with drones in vineyards

Abdrift bei der Anwendung von Pflanzenschutzmitteln mit Drohnen im Weinbau

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Abstract

Field experiments according to ISO 22866 were conducted to determine the spray drift from Unmanned Aerial Spraying Systems (UASS) applying plant protection products (PPP) in vineyards in order to collect data that can be used for drift risk assessment by authorities.

Different octocopters, nozzles (standard and air induction), application parameters (height, speed) and flight patterns (longitudinal and lateral flight lines) were used. The drift sediment at distances up to 20 m was compared to the German basic drift values for crewed helicopters and ground based air blast sprayers.

In comparison to PPP applications with crewed helicopters, the spray drift risk is substantially lower when using UASSs. For air induction nozzles, the 90th percentile values of drift sediment are even lower than the basic drift values for ground equipment.

This is why, similar to crewed helicopters, UASSs should be equipped with drift reducing atomisers, such as air induction nozzles. Providing this, the existing basic drift values for vineyards would apply also for drift risk assessment for UASS applications.

Keywords

Unmanned Aerial Spraying System, drone, spray drift, vineyard, basic drift values

Zusammenfassung

Es wurden Feldversuche nach ISO 22866 zur Bestimmung der Abdrift bei der Anwendung von Pflanzenschutzmitteln mit Drohnen im Weinbau durchgeführt, um Messwerte zu gewinnen, die von Behörden für die Risikobewertung verwendet werden können.

Verschiedene Oktokopter, die mit unterschiedlichen Düsen (Standard- und Injektordüsen) ausgestattet waren, wurden mit unterschiedlichen Applikationsparametern (Fluggeschwindigkeit, -höhe und –richtung) eingesetzt. Das Abdriftsediment wurde für Entfernungen bis 20 m bestimmt und mit den Abdrifteckwerten für den Weinbau für Bodengeräte und Hubschrauber verglichen.

Im Vergleich zu den Werten für Hubschrauber ist die Abdrift für Drohnen im Weinbau wesentlich geringer. Werden Injektordüsen eingesetzt, sind die 90sten Perzentile des Abdriftsediments für Drohnen sogar geringer als die Abdrifteckwerte für Bodengeräte.

Deshalb wird vorgeschlagen, Spritzeinrichtungen für Drohnen ausschließlich mit Abdrift mindernden Zerstäubern, wie Injektordüsen, auszurüsten. Unter dieser Voraussetzung können die etablierten Abdrifteckwerte für Bodengeräte im Weinbau auch für die Risikobewertung bei der Anwendung mit Drohnen verwendet werden.

Stichwörter

UAV, Drohne, Abdrift, Weinbau, Abdrifteckwerte

Introduction

When applying plant protection products (PPP), spray drift is one of the major hazards for non-target organisms downwind from the treated areas. German authorities responsible for the authorisation of PPPs have been using empirical models for drift risk assessment for decades, the so-called basic drift values. These curves are the result of a number of field tests with conventional application techniques and represent the 90th percentile of drift sediment values at different distances

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from the treated field. They are available for different applications and types of crops, such as arable crops, orchards or vineyards (BVL, 2020).

In Germany, a considerable amount of grapes is produced in vineyards on steep slopes with an inclination of at least 30%. Strub & Loose (2016) estimated that this applies to an area of 14.000 ha which corresponds to approximately 14% of the total German vine growing area.

According to European (EU, 2009) and German (DE, 2012) legislation, aerial application of plant protection products is prohibited. Steep slope vineyards are eligible for derogations from this, if aerial application would cause less environmental impact compared to other application techniques and the PPP is approved for this application. This also applies to drones equipped with Unmanned Aerial Spraying Systems (UASS) that have been increasingly used worldwide for the application of PPPs. As drones shall be used in German steep slope vineyards also as a replacement for crewed helicopter applications, the authorisation of PPPs for these applications is necessary. Drone applications are expected to reduce the environmental impact compared to applications with helicopters. However, reliable data that can also be used for the necessary spray drift risk assessment are hardly available (OECD, 2021).

The aim of this study was to collect spray drift data from several UASSs in slope vineyards in order to compare these data with basic drift values for ground sprayers as a basis for drift risk assessment by authorities. The variation of drones, application parameters and flight patterns in this study should help to obtain results with sufficient practical relevance for a reasonable range of conditions. Different nozzles were used to identify the best available technology to reduce spray drift as required for aerial application systems by EU legislation (EU, 2009).

Materials and Methods

A spray drift study according to ISO 22866 (ISO, 2005) was conducted with several UASSs equipped with different nozzles (see Table 1).

As it was not possible to find suitable steep slope vineyards with sufficient empty downwind space, the study had to be conducted on areas with a lower inclination. The majority of experiments (no. 1 to 8) took place at a vineyard in the district of Weingarten (Baden), northeast of Karlsruhe (49°03'27" N; 8°33'47" E). The rows of vines were oriented north to south with a slope of 13% (7.4°). One of the tests (no. 9) was conducted in Geisenheim (49°59'38" N; 7°58'28" E) with the rows oriented northwest to southeast with a slope of 15% (8.5°). At both locations, the vine row spacing was 2 m and the height of the canopy was between 2 m and 2.2 m. The canopies were at phenological stages of BBCH 71 to 95 and had a substandard leaf density especially at test 9 when 50% of the leaves were lost already.

The tests were conducted with different octocopter drones. The DJI drones Agras MG-1S, Agras MG-1P (compared to 1S improved in range and obstacle detection) and Agras T16 were employed for the tests in Weingarten whereas a Multikopter.de EVO-X8 was used in Geisenheim. The drones used and their main parameters are shown in Figure 1. The UASSs were equipped with different nozzles, such as TeeJet XR 110-015 (standard flat fan), Albuz ATR brown (standard hollow

Table 1. Tested variants and application parameters

no.	date	stage BBCH	drone	nozzle	nozzle flow rate L/min	pressure bar	flight speed km h^{-1}	swath width m	application rate L ha^{-1}	flight hight[a] m	flight orientation[b]	replicates
1	18.07.19	79	MG-1S	4 × Airmix 110-015	1.08	2.4	9.0	2	70.8	1	longitudinal	5
2			MG-1S	4 × XR 110-015	1.1	2.4			72.1	1		5
3	16.10.19	92	MG-1P	4 × IDK 90-025	0.62	1.2	6.6	3	75.2	2	lateral	3
4			MG-1P	4 × XR 110-01	0.45	4.0	4.8		75.0	2		3
5			T16	8 × IDK 90-025	0.6	1.1	12.8		75.0	2		3
6			T16	8 × XR 110-01	0.45	4.0	9.6		75.0	2		3
7			T16	8 × IDK 90-025	0.6	1.1	12.8	3	75.0	2	longitudinal	3
8	25.10.22	95	MG-1S	4 × Airmix 110-015	0.5	2.1	5.4	3	74.1	2	lateral	4
9	10.10.19	91	EVO-X8	5 × ATR brown	0.38	3.0	7.6	2	75.4	1	longitudinal	3

[a] above canopy
[b] relative to the rows of vines

Fig. 1. Drones used for the experiments. a) DJI Agras MG-1 (max. take-off mass 24 kg, max. payload 10 kg), b) DJI Agras T16 (41 kg, 15 kg), c) Multikopter.de EVO-X8 (50 kg, 17 kg)

cone), agrotop Airmix 110-015 and Lechler IDK 90-025 (both air induction flat fan nozzles). Spray pressure and flight speed were adjusted to obtain an application rate of approximately 75 L ha^{-1} considering the swath width from the UASSs. During the application, the time needed to fly along the lines was manually measured to check the speed. Prior to the tests, the volume flow rate emitted by each nozzle was measured in order to calculate the actual application rate for each test obtained from flow rate, set swath width and flight speed (Table 1). This was monitored by measuring the volume sprayed on the treated area. The set flight height varied from 1 m to 2 m above the top of the canopy. Compliance with the set height was checked occasionally using a measuring stick.

Different flight patterns were applied (see Fig. 2). For some of the test, the drones flew in longitudinal direction along the rows beginning at the downwind side of the vineyard. The flight distance was approximately 50 m. In other tests, the same area was treated flying in lateral direction across the rows. The edge row was spared from the treatment for some tests in both cases. The orientation of the drone was forward and backwards without turning around when chanced flight direction. In all cases, broadcast spray applications were carried out differently from those described by Biglia et al. (2022) exploiting band application when flew longitudinal. The drones were operated in automatic mode during the tests on pre-defined flight lines at pre-set height and speed with the accuracy provided by the GPS navigation with a manual correction using a reference point at the test site. The positioning error was in the range of 10 cm. An RTK-DGPS was used only for test 9 in Geisenheim providing a positioning accuracy of 2 cm.

Lines of ground collectors consisting of 10 petri dishes (greiner bio-one, ref. 6391102, 145 mm in diameter) with a spacing of 1 m at downwind distances of 3 m, 5 m, 10 m, 15 m and 20 m from the edge of the field were arranged on metal planks in the longitudinal centre of the treated area to collect the spray drift sediment. According to ISO 22866, the edge of the field was considered a virtual line situated half a vines row spacing downwind from the last vines row (Fig. 2). The area downwind from the vineyard hosting the drift collectors was cropped with grass cut to 10 cm height in maximum (Fig. 3).

All tests were conducted at least 3 times. The number of actual replicates are listed in Table 1. For variant 8, 4 replications were performed but one of them (test 8.4) was excluded from evaluation since the values incomprehensively exceed-

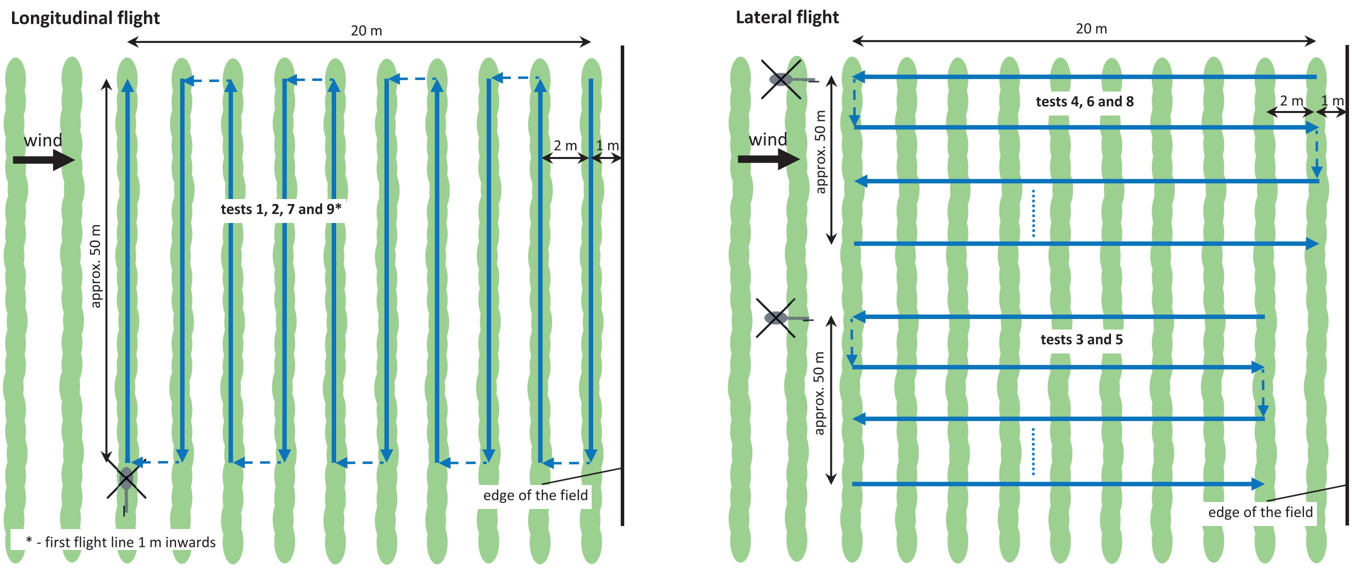

Fig. 2. Top view on the flight patterns applied for the tests. In each case, the drift sediment sampling area with 10 petri dishes at each distance of 3, 5, 10, 15 and 20 m from the edge of the field was located downwind.

Fig. 3. View on the inclined vineyard in Weingarten during a test with the drone applying the test liquid, the short grass canopy on the downwind area and the planks supporting the petri dishes for drift sediment collection

ed those from the other replicates by an order of magnitude and were therefore considered as outliers. Although the wind speed was slightly higher at this test (Table 1), it was not possible to identify any reason for this outlier.

Weather data, such as wind speed and direction as well as air temperature, were recorded using a weather station Wento-Ind (Lambrecht) installed in the longitudinal centre approximately 20 m downwind from the vineyard at 3 m height above the ground with a sample rate of 1 s^{-1}.

The spray liquid was water with Brilliant Sulfoflavine (BSF17, batch 1F-561, Waldeck) as tracer dye with a concentration of 4 g L^{-1} for tests 1 to 7 in Weingarten and with Pyranin 120% (batch CHU90294, Lanxess) with a concentration of 5 g L^{-1} in Geisenheim (test 9). Pyranin (batch CHD90018) was also used for test no. 8, with a concentration of 8 g L^{-1}. All samplers for drift deposit were collected within less than 10 min after each test and stored in a box protected from light exposure in order to minimise degradation. Considering a time for each treatment of 7 min in maximum, the total exposure time of the petri dishes to sunlight could have caused a maximum decay of fluorescence for Pyranine of about 5% (Herbst & Wygoda, 2006). As it was shown in former unpublished tests, the potential decay for BSF is even lower.

The samplers were stored in a dark, cool room and analysed within 14 days after the tests. For analyses, the tracer was extracted from the petri dishes using 50 mL (60 mL for test 9 in Geisenheim) of de-ionised water. These samples were analysed with a fluorimeter (Perkin-Elmer LS45). Samples of the spray liquid taken from a nozzle of the UASS after each treatment were diluted in de-ionised water and used as calibration liquid for the calculation of the volume of spray liquid found on each petri dish. The volume of the spray liquid V_c on each collector was calculated as:

$$V_c = \frac{C_{cl} \cdot (FL - FL_b)}{FL_c} 10^3 \cdot V_w \quad (1)$$

with

FL_b – fluorimeter reading for the blank sample

FL_c – fluorimeter reading for the calibration liquid

FL – fluorimeter reading for the sample

C_{cl} – concentration of the spraying liquid in the calibration liquid

V_w – volume of the washing liquid/ml.

From these values, the deposit d_c on each drift collector was calculated as percentage of application rate:

$$d_c = \frac{V_c}{A_c \cdot R} 10^4 \% \quad (2)$$

with

A_c – sampling area/cm^2

R – application rate/L ha^{-1}

A statistical evaluation was conducted to calculate the 90th percentile from the 30 or 50 deposit values for each downwind distance and test variant using the QUANTIL function in EXCEL2016. This method corresponds to the procedure used to establish the basic drift values for other applications as mentioned above and allows comparing them to the results of this study.

Results

The meteorological conditions for each test are listed in Table 1. The acceptance criteria for valid drift measurements defined regarding wind conditions by ISO 22866 as well as regarding the maximum air temperature of 25 °C and maximum wind speed of 5 m s^{-1} recommended by the German code of practice (BMEL, 2010) are met for almost all tests. In a few cases, the maximum deviation of the main wind direction from the perpendicular to the row orientation exceeded the limit of 30 deg slightly. Since the deviations were small, all measurements were included in the evaluation. The fraction of wind speed outliers < 1 m s^{-1} was 0% for all tests.

In total 310 drift sediment values were available per downwind distance, among them 170 from air inclusion nozzles.

The drift sediment curve representing the 90th percentiles of the measuring values from all tests are shown in Figure 4. Compared to the official basic drift values for vine representing ground based air blast sprayers (BBA, 2000), the drift values for drones, calculated for all nozzles, are a little higher. As the values for crewed helicopters are much higher than for ground based sprayers (BVL, 2020), the helicopter values are not shown in Figures 4 or 5 for clarity.

It is known from ground equipment that air induction nozzles can reduce spray drift due to the increased droplet size. This can be shown also for UASS application with a separate evaluation for the test with standard nozzles and air induction nozzles (Fig. 5). Using air induction nozzles, the 90th percentile values at all downwind distances are lower than the basic drift values for vine.

A data set with all test details, drift sediment data as well as the detailed weather conditions is available from Herbst et al. (2023).

Discussion and conclusions

The spray drift values found in this study are the result of a collection of tests with different UASSs, nozzle types and applications. Although it was not possible to systematically combine all the influencing factors and the number of tests was too low to quantify the impact of these factors on spray drift, the test

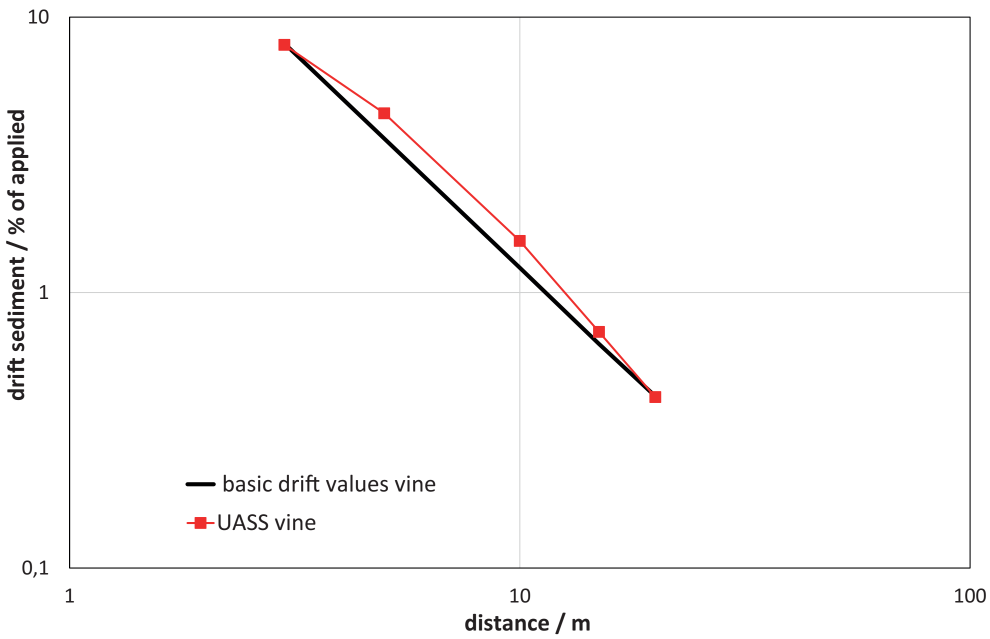

Fig. 4. 90th percentiles of drift sediment from all measurements compared to the basic drift values for ground based equipment for vineyards.

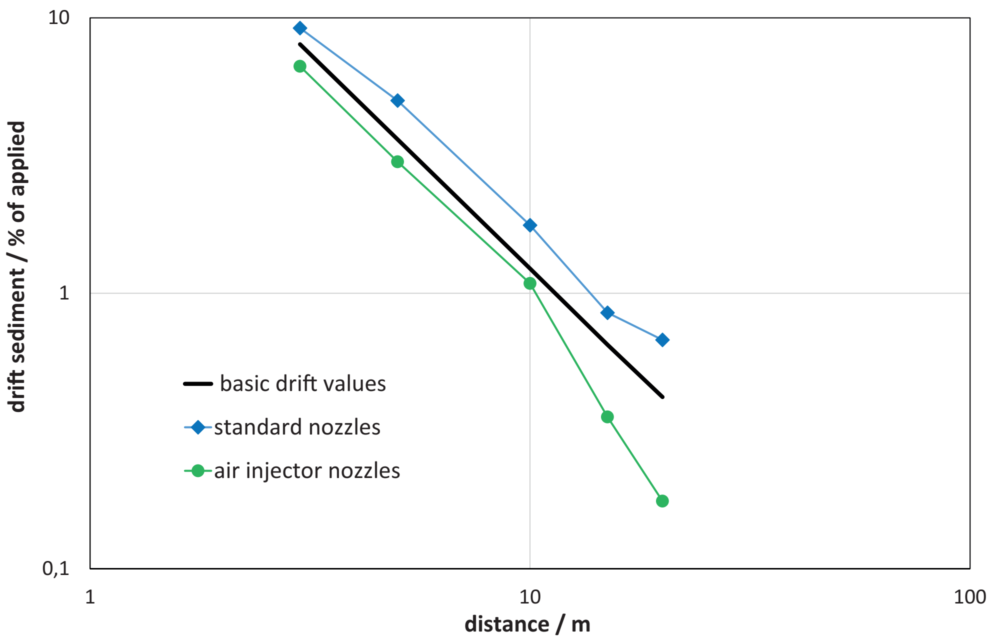

Fig. 5. 90th percentiles of drift sediment from different nozzle designs compared to the basic drift values for ground based equipment for vineyards.

Table 2. Average meteorological conditions for each test (in brackets: acceptance criteria according to ISO 22866 or German code of practice)

test.replicate	wind speed $m\ s^{-1}$ ($\leq 5\ m\ s^{-1}$)	deviation wind direction deg ($\leq$ 30 deg)	fraction of wind direction deviations < 45° % (< 30%)	temperature °C ($\leq$ 25 °C)	air humidity % ($\geq$ 30%)
1.1	2.1	19.9	4.7	20.0	64.2
1.2	2.1	17.4	4.0	20.4	63.5
1.3	2.4	20.8	4.7	20.9	61.5
1.4	2.7	20.8	3.2	21.0	58.8
1.5	2.5	19.0	6.6	21.5	57.3
2.1	2.7	14.9	1.9	22.2	55.0
2.2	2.5	27.3	8.5	22.6	53.8
2.3	2.5	22.4	11.4	23.2	52.3
2.4	2.5	24.7	14.7	23.5	51.4
2.5	2.8	19.7	7.5	24.1	50.6
3.1	2.5	28.4	11.7	13.6	72.0
3.2	3.2	22.5	7.6	13.2	72.6
3.3	2.4	29.4	17.5	13.5	73.4
4.1	2.6	**30.1**	15.2	13.3	73.0
4.2	2.4	24.4	9.1	15.5	68.5
4.3	3.5	20.5	9.3	15.9	66.0
5.1	3.6	24.0	12.1	17.1	62.0
5.2	3.1	24.6	8.5	16.5	63.1
5.3	3.9	16.1	0.0	17.2	60.1
6.1	3.3	18.2	2.1	16.8	63.2
6.2	4.2	19.3	1.7	16.6	61.8
6.3	3.9	20.1	1.4	16.8	60.3
7.1	3.9	20.8	7.2	18.5	56.0
7.2	5.0	10.8	0.0	18.4	55.4
7.3	3.3	**32.0**	20.7	17.9	57.0
8.1	2.1	20.2	4.5	15.1	76.6
8.2	2.1	31.4	19.8	16.8	73.1
8.3	1.7	19.7	7.9	18.6	66.2
8.4	3.2	13.6	0.3	17.3	73.1
9.1	2.8	19.9	17.9	13.4	61.7
9.2	3.5	0.6	7.2	13.9	60.3
9.3	2.7	1.9	13.0	13.8	61.0

variants include longitudinal and lateral flights, flight heights up to 2 m above the canopy as well as flight speeds up to 13 $km\ h^{-1}$ and therefore represent a reasonable range of practical application scenarios for drones in German steep slope vineyards. The design of the drones used for the tests did not vary substantially. It was shown by Herbst et al. (2020), though, that different designs of drones (mass, number of rotors) did not significantly influence the amount of spray drift.

In comparison to PPP applications with crewed helicopters, the spray drift risk is substantially lower when using UASSs (BVL, 2020). This as well as other advantages, such as reduced requirements regarding infrastructure and pilot qualification, are indicative for replacing helicopters by drones for PPP application in steep slope vineyards. According to EU legislation (EU, 2009), aerial spraying systems shall be equipped with the best available technology to reduce spray drift. It was clearly shown that for UASSs standard nozzles do not comply with this requirement. This is why, similar to crewed helicopters, UASSs should be equipped with drift reducing atomisers, such as air induction nozzles. Providing this, the existing basic drift values for vineyards would apply also for UASS applications.

It is assumed that the results of this study provide an appropriate first basis for drift risk assessment for PPP applications in steep slope vineyards taking into account also the limited scale of this application in Germany. The whole data set produced in this study is published (Herbst et al., 2023) to enable a more detailed analysis of the results. Further spray drift tests will be helpful to broaden this basic data set, also considering the upcoming use of rotary atomisers for PPP application with UASSs.

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Conflicts of interest

The author(s) declare that they do not have any conflicts of interest.

Data availability

A data set with all test details, drift sediment data as well as the detailed weather conditions is available under https://doi.org/10.5073/20230328-170409-0.

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A model canopy for spray drift measurements in orchards

Eine Modellanlage für Abdriftmessungen im Obstbau

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Abstract

A model canopy offers the advantage of being able to compare drift characteristics of sprayers under standardized conditions and independently from the season.

A steel structure covered with a net similar to the EvaSprayViti viticulture test stand was developed to mimic a common orchard. The selection of the net was made on the basis of preliminary tests on droplet and wind permeability. A net with mesh size of 1.38 mm by 1.38 mm was found best suited to reproduce the characteristics of a natural foliage and was used to cover the six-row model layout.

Drift measurements were carried out with different types of sprayer design in the model system and in orchards. The drift reduction values showed a good congruence. The drift behaviour of the sprayers could be realistically reproduced in the model system. The effect of different nozzles and reduced working pressure could also be shown in the model canopy. Further measurements at other locations are required to demonstrate reproducibility.

Keywords

air-assisted sprayer, spray drift measurements, model canopy, orchards

Zusammenfassung

Eine Modellanlage bietet den Vorteil, die Abdrifteigenschaften von Sprühgeräten unter standardisierten Bedingungen und unabhängig von der Saison vergleichen zu können.

Ein Modul aus Stahl, bespannt mit einem Netz, wurde in Anlehnung an den Weinbau-Prüfstand EvaSprayViti entwickelt, um eine Obstanlage zu simulieren. Die Auswahl des Netzes wurde anhand von Vorversuchen zur Tropfen- und Winddurchlässigkeit vorgenommen. Ein Netz mit der Maschenweite 1,38 mm × 1,38 mm, konnte die Charakteristik einer natürlichen Laubwand am besten nachstellen und wurde so zur Bespannung der sechsreihigen Modellanlage verwendet.

Es wurden Abdriftmessungen mit unterschiedlichen Gebläsetypen in der Modellanlage und in Obstanlagen durchgeführt. Die erreichten Abdriftminderungswerte zeigten weitestgehend eine gute Übereinstimmung. Das Abdriftverhalten der Sprühgeräte konnte in der Modellanlage realistisch abgebildet werden. Ebenso konnte der Effekt von unterschiedlicher Düsen und reduzierter Arbeitsdruck in der Modellanlage aufgezeigt werden. Weitere Messungen an anderen Standorten sind erforderlich, um die Reproduzierbarkeit aufzuzeigen.

Stichwörter

Sprühgeräte, Abdriftmessungen, Modellanlage, Obstanlage

Introduction

So far, drift studies with air-assisted sprayers have been carried out in natural orchards. It is often difficult to find an orchard that meets the requirements specified by JKI guideline 7-1.5 (JKI, 2013a). As in course of the season development stage and leaf condition of trees change, directly comparable measurements of different sprayers are only possible in a very narrow time slot. Recently, measurements have been carried out on the open space without a canopy and drift data were corrected with conversion factors. The reproducibility of the results using this approach is limited though. These problems could be solved by simulating the orchard canopy using an artificial structure similar to the EvaSprayViti test rig used for vineyard sprayers in France (Codis et al., 2013).

The aim of this study was to design a model canopy for spray drift measurement in orchards under standardized and reproducible conditions, independent from the season and with direct access at the location of LTZ. This shall be used especially to compare the influence of different types of sprayers, sprayer settings, nozzles or application parameters on spray drift for the official rating of Drift Reducing Techniques (DRT). A steel module was developed oriented on the EvaSprayViti viticulture test stand (Codis et al., 2013). The design of the frame should meet the shape of a small spindle pruning at late growing stages. To get a similar filter effect in the model canopy like in the

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natural foliage, different preliminary tests were carried out. In a wind channel, five different nets were compared according to permeability of drops and airflow. With the results, a selection of three nets was made, which were examined in a further preliminary test with regard to the permeability of drops and airflow. One module was mounted in an orchard. In a direct comparison of model and natural canopy, ground sediment and wind speed were measured. For both parameters, net type "Giro 80" showed good correlation with the natural canopy.

Material and Methods

One module of the model canopy is 6 m long and 3.5 m high. The trunk sector starts from a height of 50 cm and the canopy is 80 cm wide. In order to meet the treatment areas 50 m in length and 20 m in width of the JKI guideline 7-1.5 (JKI, 2013a), six rows were set up, each with six modules and a row spacing of 3.5 m. Steel frames are covered with a net on both sides. The used net (Giro 80, Whailexx) has a mesh size of 1.38 mm by 1.38 mm.

A spray drift study was conducted with several air-assisted sprayers equipped with different nozzles (see Table 1) according to ISO 22866 (ISO, 2005) in the model canopy at Rheinstetten Forchheim (48°96'92.5"N; 8°34'07.3"E) (Fig. 1). For comparison of that, drift measurements were conducted in two commercial apple orchard plantations. One was located at Karlsruhe Durlach (49°00'13.7"N; 8°29'33.5"E) which was planted with Braeburn. Row distance was 3.5 m and canopy height of 3.5 m. At

Table 1. Tested variants and application parameters

no.	manufacturer	type	fan type	nozzles	pressure bar	AR_{mc} [a] L ha^{-1}	AR_{o} [b] L ha^{-1}	pto speed 1 min^{-1}	gear
1	Wanner	SZA 32	axial	16 × ITR 80-01 C	10	284	249	540	2
2			axial	16 × ITR 80-01 C	5	213	187	400	1
3			axial	16 × TVI 80-01	11	302	264	540	2
4	Wanner	K 42 GA	axial	16/14 × IDK 90-02 C	10	592	497	320	1
5	Mitterer	10 81 VV	axial	16 × IDK 90-02 C	10	524	524	310	1
6	Wanner	32 TWIN	double axial	18 × IDK 90-02 C	10	639	639	320	1
7	Vicar	NT 456	radial	12 × IDK 90-02 C	10	426	426	350	1
8	Vicar	NT 540	radial	16 × IDK 90-02 C	10	568	568	350	1
9	Weber	QU 17	tangential	18 × IDK 90-02 C	10	639	639	hydraulic driven	

[a] application rate model canopy
[b] application rate orchard

Fig. 1. Drift measurement in the model canopy with an air assisted sprayer.

Ensingen (48°57'48.2"N; 8°56'42.6"E) Topas was planted with 4.0 m row distance and a canopy height of 3.0 m. The canopies were at phenological stages of BBCH 72 to 75.

Tests were conducted with different type of air-assisted sprayers. Three axial, one double axial, two radial and one tangential fan. All sprayers were equipped with air induction flat fan nozzles (Lechler IDK 90-02 C, Albuz TVI 80-01) or air induction hollow cone nozzles (Lechler ITR 80-01 C). Forward speed in each variant was 7.0 km h^{-1}. Spray pressure was for most variants at 10.0 bar. Application rate was in the range of 429 – 639 L ha^{-1}, because of different number of nozzles. For example, the radial fan Vicar NT 456 is equipped with 12 nozzles and the double axial fan Wanner 32 Twin with 18 nozzles.

Lines of ground collectors consisting of 10 petri dishes (145 cm^2 surface area) with a spacing of 1 m at each downwind distance of 3 m, 5 m, 10 m, 15 m and 20 m from the edge of the field were arranged in the longitudinal centre of the treated area to collect the spray drift sediment. Each measurement was done in threefold replication. Weather data, such as wind speed and direction as well as air temperature and relative humidity, were recorded with a sample rate of 1 s^{-1} in the centre axis behind the measuring area in 1 m height above the canopy.

Spray liquid was water with Brilliant Sulfoflavine (BSF) as tracer dye with a concentration of 1 g L^{-1} for tests number 1 to 8 and Pyranin with a concentration of 2 g L^{-1} (no. 9). All samplers for drift were collected immediately after each test. Samples of the spray liquid were taken from the sprayers after each treatment. All samples were stored in a box protected from light exposure in order to minimise degradation.

The samplers were stored in a dark, cool room and analysed within 14 days after the tests with a fluorimeter Perkin Elmer LS45. For analyses, the tracer was extracted from the petri dishes using 50 ml de-ionised water. Samples of the spray liquid were analysed within 3 days after tests. Therefore, tank samples were diluted in de-ionised water and used as calibration liquid. The volume of the spray liquid V_c on each collector was calculated as:

$$V_c = \frac{\overset{c}{C_{cl}} \cdot (FL - FL_b)}{FL_c} 10^3 \cdot V_w \quad (1)$$

with

C_{cl} – concentration of the spraying liquid in the calibration liquid

FL – fluorimeter reading for the sample

FL_b – fluorimeter reading for the blanks (collector and de-ionised water)

FL_c – fluorimeter reading for the calibration liquid

V_w – volume of the washing liquid/ml.

From these values, the deposit d_c on each drift collector was calculated as percentage of application rate:

$$d_c = \frac{V_c}{A_{col} \cdot AR} 10^4 \% \quad (2)$$

with

A_{col} – collector area/cm^2

AR – application rate/L ha^{-1}

A statistical evaluation was conducted to calculate the median from the 30 deposit values for each downwind distance and test variant. The median is compared to the basis values “orchard-late” (JKI, 2013b) and its drift reduction classes 50 %, 75 %, 90 % and 95 %. This method corresponds to the procedure for the registration of plant protection equipment in the section “drift-reduction” of the register of loss reducing equipment of the descriptive list used to establish the basic drift values, which is outlined in the JKI guidelines 2-2.1 (JKI, 2013b).

Additionally the reduction R for each median was calculated as:

$$R = \frac{(BV - M)}{BV} \; 100 \quad (3)$$

BV – basis value

M – median

Results

The meteorological conditions for each test are listed in Table 2. The acceptance criteria for valid drift measurements

Table 2. Average meteorological conditions for each test (in brackets: acceptance criteria according to ISO 22866 or German code of practice)

replication	wind speed m s^{-1} (≤ 5 m s^{-1})	deviation wind direction deg (≤ 30 deg)	temperature °C (≤ 25 °C)	air humidity % (≥ 30%)
1.1 mc	3.0	29.7	16.5	67.0
1.2 mc	3.4	29.1	16.5	67.0
1.3 mc	2.4	39.4	16.5	67.0
1.1 o	2.5	22.6	13.4	68.4
1.2 o	3.1	28.6	14.4	68.5
1.3 o	3.5	21.9	13.1	68.9
2.1 mc	2.8	**39.1**	**25.1**	31.2
2.2 mc	2.8	**37.3**	**25.2**	31.4
2.3 mc	2.9	**39.2**	**25.4**	31.6
2.1 o	2.8	16.4	13.0	68.9

* mc model canopy, o orchard

Table 2. Continued

replication	wind speed m s^{-1} (≤ 5 m s^{-1})	deviation wind direction deg (≤ 30 deg)	temperature °C (≤ 25 °C)	air humidity % (≥ 30%)
2.2 o	2.6	24.1	12.9	68.3
2.3 o	2.6	18.1	12.9	68.4
3.1 mc	2.4	**37.5**	18.1	63.8
3.2 mc	2.4	30.0	18.9	60.0
3.3 mc	2.1	**45.0**	18.3	60.8
3.1 o	2.8	20.7	13.6	65.7
3.2 o	2.5	21.3	13.7	64.4
3.3 o	4.0	23.1	13.6	64.2
4.1 mc	2.1	**32.8**	18.0	57.3
4.2 mc	2.4	**42.5**	18.6	49.2
4.3 mc	2.9	**37.0**	18.6	49.2
4.1 o	2.4	25.9	7.5	83.0
4.2 o	2.6	25.6	7.6	82.7
4.3 o	2.2	23.6	7.5	83.5
5.1 mc	1.8	**31.7**	22.4	43.8
5.2 mc	2.4	28.4	26.1	32.5
5.3 mc	3.1	26.6	26.7	30.8
5.1 o	2.6	26.3	22.3	39.5
5.2 o	2.1	26.8	23.0	47.1
5.3 o	2.7	22.0	23.2	45.8
6.1 mc	2.6	**39.5**	13.1	77.7
6.2 mc	3.0	**34.7**	14.0	74.6
6.3 mc	2.9	**38.0**	13.2	77.7
6.1 o	2.9	29.6	16.3	71.5
6.2 o	3.1	27.5	15.3	72.6
6.3 o	2.6	28.5	16.1	72.0
7.1 mc	2.4	**32.7**	**26.7**	47.8
7.2 mc	2.2	29.1	**26.9**	47.0
7.3 mc	2.7	**36.1**	**27.2**	45.6
7.1 o	3.3	18.9	17.3	63.4
7.2 o	2.4	27.7	18.6	57.6
7.3 o	2.6	26.7	18.6	57.7
8.1 mc	2.4	**33.0**	**27.4**	30.0
8.2 mc	2.1	**34.5**	**27.6**	31.1
8.3 mc	2.6	**35.0**	**27.2**	32.5
8.1 o	2.9	22.6	21.9	44.8
8.2 o	2.6	27.1	21.4	45.2
8.3 o	2.7	25.4	21.5	43.9
9.1 mc	2.1	**48.9**	15.5	56.4
9.2 mc	2.3	**46.9**	15.6	53.7
9.3 mc	1.9	**35.6**	15.0	56.3
9.1 o	3.3	15.0	24.7	32.7
9.2 o	2.6	24.2	24.4	30.6
9.3 o	2.8	22.0	24.0	33.2

* mc model canopy, o orchard

defined regarding wind conditions by ISO 22866 (ISO 2005) and regarding the maximum air temperature recommended by the German code of good practice are met for all tests in the orchards. For most of the tests in the model canopy, the deviation wind direction was higher than the limit of 30 degrees and in a few cases air temperature was higher than the limit 25 °C.

In Table 3 the reduction in percent for each variant and each distance as well as the average are shown. Average values have minor difference, but several single values have large variation. Variant no. 1 and no. 6 showed the smallest deviation in the average reduction values with 0.1 and 0.6 percentage point difference. The biggest deviation show variation no. 3 with 18.4 percentage points difference. In all other cases, the difference of the average reduction value between model canopy and orchard was between 1.0 and 6.9 percentage points.

In Figure 2 basic values, drift classes and ground sediment are shown exemplary with variant no. 9. In this case the values measured in the orchard are higher than the values measured in the model canopy. Figure 3 shows drift reduction values for all variants. For variant 1, 5, 6 and 9 the results regarding DRT rating of model canopy and orchard are the same. For all other variants drift reduction class deviates.

Discussion and conclusions

The spray drift values found in this study are the result of tests with different designed air assisted sprayers. With the exception of tunnel sprayers, all in Germany common used fan types are represented in the line-up. Meteorological conditions for tests in the model canopy showed a problem by exceeding limit for deviation of the main wind direction. A forest in the background of the model canopy in a distance of approximately 50 m might explain this effect. But the biggest difference of the values shows variant no. 3. Repetition 3.3 o with an average wind speed of 4.0 m s^{-1} adds the highest sediment values in this variant. The effect of wind speed overlies wind direction. For further measurements in the model canopy, it should be set up at a different location to avoid potential wind jams by the forest.

Nevertheless values for variant nos. 1 and 2 shows that the effect of application parameters, including fan speed and working pressure, can be measured in the model canopy. Variant nos. 1 and 6 showed the smallest difference between model canopy and orchards. In addition, all other variants besides no. 3, showed a good congruence. Focusing on the DRT rating in Figure 3, small deviations are obvious that can result in different drift reduction classes without any clear trend. Comparing variants 1, 4, 5 and 8, reduction in orchard was higher, for variants 2, 3, 6, 7 and 9 reduction in model canopy was higher. The design of the model system comes very close to the structure and characteristics of a natural orchard. Drift behaviour of sprayers can be realistically measured in the model canopy. Repetition of tests are required for measurements with critical meteorological parameters at another location. In addition, repetitions of different variants should be carried out to demonstrate reproducibility.

In order to compare sprayers in the model canopy in future or to make classifications regarding drift reduction based on data measured in the model canopy, it is necessary to describe the system in a JKI guideline or ISO standard. This requires a series of further measurements by different institutes. As soon

Table 3. Reduction in % for each variant and each distance.

variant		3 m	5 m	10 m	15 m	20 m	average
1	mc	88.7	82.2	78.3	76.4	71.7	79.5
	o	84.9	77.9	81.6	75.6	78.1	79.6
2	mc	98.1	97.2	96.6	96.2	94.2	96.5
	o	95.8	94.7	95.4	92.7	94.3	94.6
3	mc	90.2	83.2	82.3	82.1	78.4	83.2
	o	72.2	68.5	66.1	50.5	66.8	64.8
4	mc	97.3	95.5	91.6	90.1	92.3	93.4
	o	97.5	97.7	97.9	97.7	96.8	97.5
5	mc	95.7	93.9	91.2	89.3	88.2	91.7
	o	95.9	96.6	94.6	90.6	90.4	93.6
6	mc	92.6	89.6	89.1	90.2	86.8	89.7
	o	83.6	89.5	91.8	91.5	89.3	89.1
7	mc	98.0	97.6	97.0	96.2	93.3	96.4
	o	95.9	96.1	95.2	92.1	90.7	94.0
8	mc	92.0	88.8	90.1	86.4	77.3	86.9
	o	94.2	94.2	93.3	93.8	93.7	93.8
9	mc	98.4	98.6	97.9	98.0	98.0	98.2
	o	97.4	97.3	97.6	97.2	96.3	97.2

* mc model canopy, o orchard

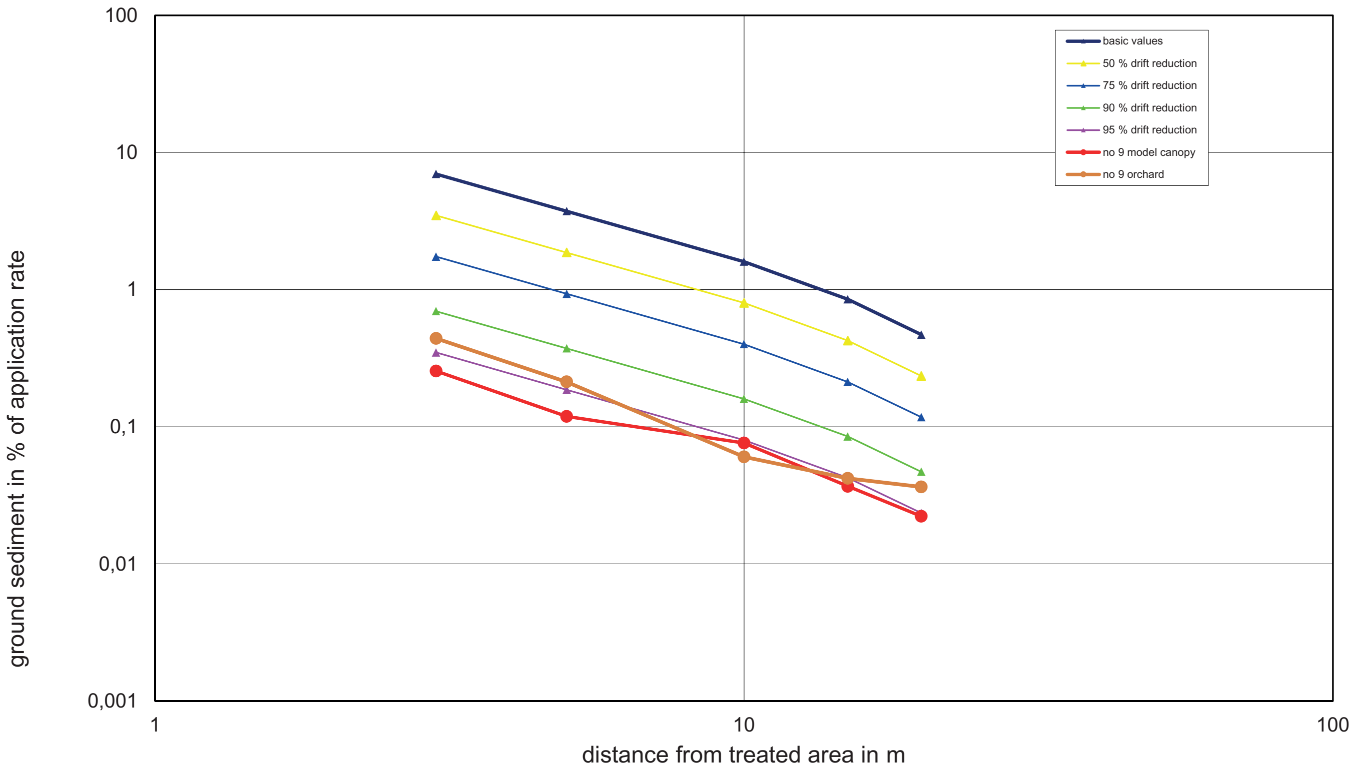

Fig. 2. Basic values, drift classes and classification of variant no 9 in the model canopy as well as orchard.

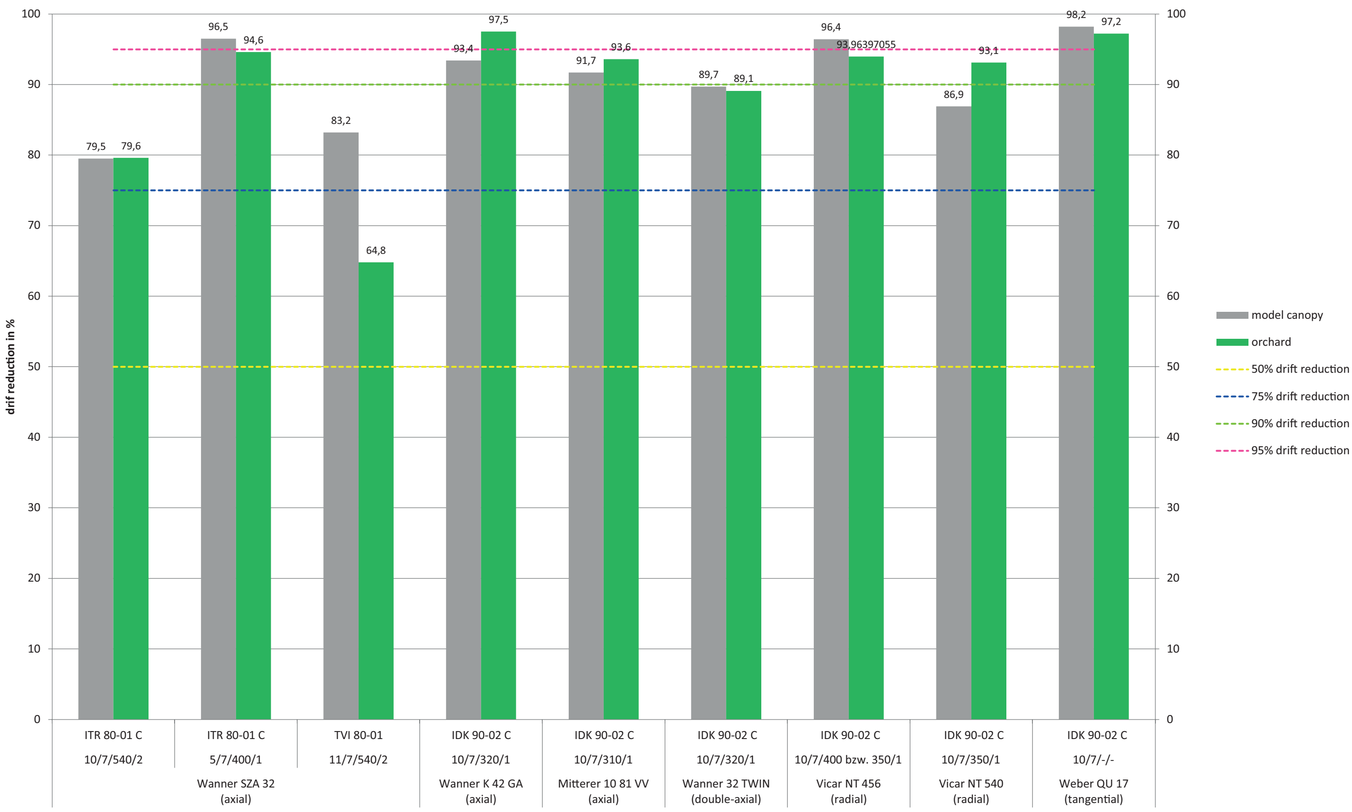

Fig. 3. Drift reduction of all variants.

as results from the comparable model canopies at Julius Kühn Institute and at ESTEBURG Obstbauzentrum Jork are available, the reproducibility can be verified.

Acknowledgments

The authors wish to acknowledge Lisa Engelhardt from the Center for Agricultural Technology Augustenberg and all the other technical staff for their help on the field and in the lab. Special thanks also to Ministerium für Ernährung, Ländlichen Raum und Verbraucherschutz (MLR) for the financial support for the field tests.

Conflicts of interest

The author(s) declare that they do not have any conflicts of interest.

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Tina Langkamp-Wedde

Basic drift values in the authorisation procedure for biocidal products (PT 18)

Abdrifteckwerte im Zulassungsverfahren für Biozidprodukte (PT 18)

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Abstract

Biocidal products are very diverse. Therefore, biocidal products are divided into 4 main groups and 22 product types. Product type 18 includes products for the control of insects, acaricides and agents against other arthropods. There is an overlap of products for plant protection, but biocides are subject to their own regulation, the Biocidal Products Regulation. In addition, in contrast to plant protection, it is not known how and where the biocidal products are used, what environmental impact these products have and what measures can be taken to minimise the environmental impact. Thus, there is no scientific knowledge available for the risk assessment of biocidal products. On behalf of the Federal Environment Agency, the JKI carried out large-scale measurements of drift at various application areas, such as solitary tree, avenue and forest edge, and with various devices, such as cannon sprayer, helicopter and UAV, for the control of the oak processionary moth. The result was a list of recommended basic drift values for three application areas in combination with five devices. At the beginning of 2022, these basic drift values were recognised by the member states of the European Commission and will in future be included in the risk assessment of biocidal products for the control of the oak processionary moth.

Keywords

Biocidal products, drift measurement, basic drift values, oak processionary moth controlling

Zusammenfassung

Biozidprodukte sind sehr vielfältig. Daher werden Biozidprodukte in 4 Hauptgruppen und 22 Produkttypen unterteilt. Der Produkttyp 18 umfasst Produkte zur Bekämpfung von Insekten, Akarizide und Mittel gegen andere Arthropoden. Eine Überschneidung der Produkte zum Pflanzenschutz liegt vor, jedoch unterliegen Biozide einer eigenen Verordnung, der Biozidverordnung. Zudem ist im Gegensatz zum Pflanzenschutz nicht bekannt, wie und wo die Biozidprodukte angewendet werden, welchen Umwelteinfluss diese Produkte ausüben und welche Maßnahmen zur Minimierung des Umwelteintrages vorgenommen werden können. Es liegen somit keine wissenschaftlichen Erkenntnisse zur Risikobewertung von Biozidprodukten vor. Im Auftrag vom Umweltbundesamt führte das JKI großangelegte Messungen zur Abdrift an verschiedenen Anwendungsbereichen, wie Einzelbaum, Allee und Waldrand, und mit verschiedenen Geräten, wie Sprühkanone, Hubschrauber und UAV, zur Bekämpfung des Eichenprozessionsspinners durch. Heraus kam eine Liste von empfohlenen Abdrifteckwerten für drei Anwendungsbereichen in Kombination mit fünf Geräten. Anfang 2022 wurden diese Abdrifteckwerte von den Mitgliedsstaaten der Europäischen Kommission anerkannt und werden in Zukunft in die Risikobewertung von Biozidprodukten für die Bekämpfung des Eichenprozessionsspinners einfließen.

Stichwörter

Biozidprodukte, Abdriftmessung, Abdrifteckwerte, Eichenprozessionsspinnerbekämpfung

Introduction

Biocidal products are pesticides that are used to protect people, animals and materials from vermin, pests and harmful organisms (EU, 2012). According to this, people are using unconsciously or consciously biocidal products as insect spray, facade protection, wood stain, disinfectant or shoe polish. However, not every user knows how to handle these products, as they are freely available and not everyone reads the warnings, which can lead to considerable environmental impacts. What is also not known to everyone is that façade paints used to protect house façades contain active substances that may no longer be used in plant protection and that there are significant environmental discharges when toxic degradation products enter the groundwater as a result of precipitation events (UBA, 2017). To prevent this and other misuse of biocidal products, the Biocidal Products Regulation coordinates the placing on the market and use of biocidal

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products. The aim of this regulation is to identify potential risks that may arise from the use of biocidal products for human and animal health or for the environment and to derive appropriate measures to ensure the safe use of biocidal products (EU, 2012). A large number of biocidal products on the market are currently subject to transitional arrangements, as they were already on the market before the deadline of 14 May 2000. These active substances and products can still be marketed untested. It is expected to take until 2024 for all biocidal products to be tested and officially authorised across the EU (ECHA, 2022b). Lack of knowledge about how biocidal products are used in the different product types delays the testing of the products.

The field of application of biocidal products is very diverse. Therefore, biocidal products have been divided into 4 main groups and 22 product types. Main group 3 Pest control contains product type 18 with insecticides, acaricides and agents against other arthropods. At first view, there are a few overlaps, but on closer inspection, there are major differences, especially in the regulation of authorisation. In the field of plant protection, research on drift has been going on for 30 years. Basic drift values for drift are based on more than 100 trials for different application areas such as arable crops, orchards, vines and hops. Lists of approved plant protection nozzles and drift reducing devices are also maintained. All these data contribute to the risk assessment of plant protection products. In the biocide sector, there is no knowledge about the areas in which products of product type 18 are applied, how they are applied in practice, whether and how they reach adjacent environmental compartments and what measures can be taken to reduce drift. There is therefore no scientific basis for a risk assessment of biocidal products. The Julius Kühn Institute (JKI), Institute for Application Techniques in Plant Protection, was then commissioned by the Federal Environment Agency to close these gaps in knowledge due to its great expertise in the field of drift measurement. An obvious question is whether the basic drift values from plant protection can be adopted for the biocide sector. To answer this question, the JKI has been working on measuring drift in biocide applications since 2017. The main tasks of this research project are: Identification of applications with high drift potential, measurement of drift in the application of biocides, calculation of basic drift values for the risk assessment, and development of drift mitigation measures for risk management and sustainable use of biocides.

Material and Method

Literature and market research show that oak processionary moth (OPM) control is an application with high drift potential. Challenging, however, is that oak processionary moth control involves not just one system, but a variety of devices with different spraying systems and types of atomisation. Cannon sprayers with pneumatic or hydraulic atomisation, helicopters with attached Simplex systems, unmanned aerial vehicles with spraying equipment or motorised knapsack sprayers with pneumatic atomisation from a lifting platform can be used. The reason for this large variety of equipment is the wide variation in the field of application areas. For example, OPM have been observed on solitary trees, on oak avenues or on forest edges and can/must be controlled there to protect the public. Thus, different devices can be used depending on the area of application. Table 1 shows an overview of the devices and the application areas that were used for the drift measurement.

For the drift measurement in the use of biocides, the JKI guideline 7.1-5 "Measuring of direct drift when applying plant protection products outdoors" (JKI, 2013) was used. According to this guideline, more than 100 trials were carried out after the basic drift values for plant protection had been determined. For the biocide sector, there is currently no guideline according to which drift tests should be carried out. For this reason this guideline was taken from the plant protection sector. According to this guideline, the application areas shown in Table 1 were divided into treated area and measuring area. The measuring area is located next to the treated area on the downwind side. Petri dishes with a diameter of 145 mm, which collect the drift as ground sediment, were distributed on wooden slats on the measuring area. According to JKI guideline 7-1.5, the Petri dishes are distributed in such a way that a representative section of the entire drift is recorded. The measuring distances to the crown edge of the treated area were 5, 10, 20, 30, 50, 75 and 85 or 100 m, depending on the size of the measuring area. At each measuring distance, 10 collectors were set up at a distance of 2 m from each other. Since the drift from the treatment of a solitary tree had never been measured before, the guideline was slightly adjusted here. In this case, the Petri dishes were placed in a V-shape on the downwind side in order to capture a large part of the total drift (Fig. 1, Table S.).

Five minutes after each treatment, 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.

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 (trade name: Pyranine 120%, colour index: Solvent Green 7) and has a recovery rate of almost 100% (Herbst & Wygoda, 2006). Herbst

Table 1. List of techniques and areas where direct environmental exposure through drift can occur and was measured.

Application technique	Application area
Cannon sprayer (pneumatic atomizer)	Solitary tree
	Avenue
	Forest edge
Helicopter	Avenue
	Forest edge
UAV	Solitary tree
Motorised knapsack mistblower	Solitary tree
Cannon sprayer (hydraulic atomizer)	Avenue

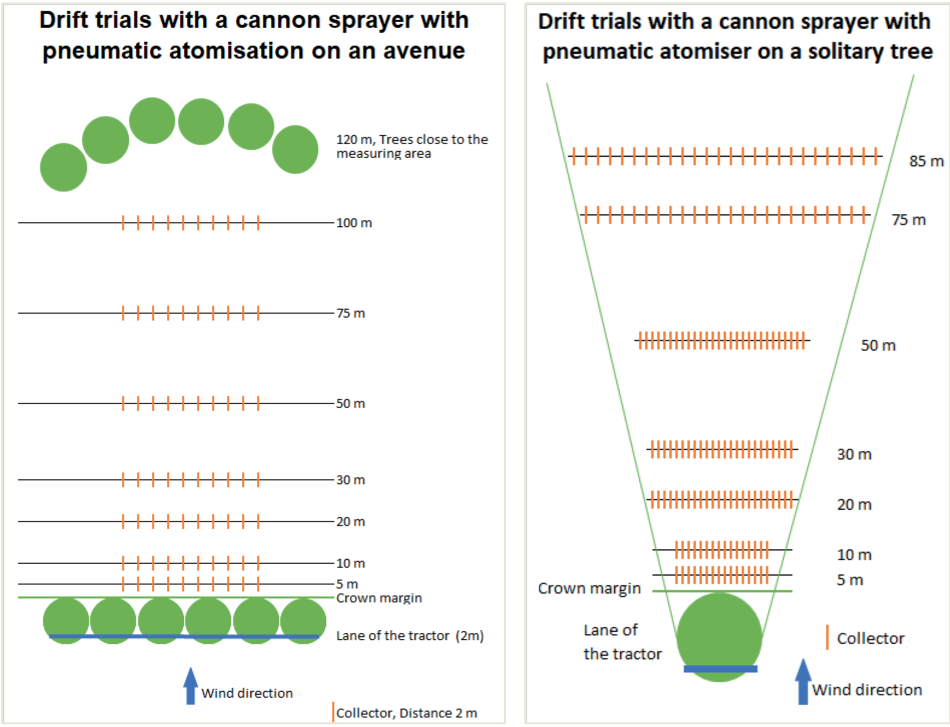

Fig. 1. Schematic illustration of the trial area avenue with a "normal" measuring area (left) and of the trial area solitary tree with a slightly adjusted measuring area (right).

& Wygoda (2006) 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. For this reason, the collectors were immediately protected from light. Tank samples were taken during the trials to check the application rate and to determine whether the tracer concentration was stable throughout the application. For the analysis, the tracer 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 concentration 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.

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

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

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 equation 2:

$$\beta_{dep\%} = \frac{\beta_{dep}}{TR} * 100\ \% \quad (2)$$

where $\beta_{dep\%}$ is the spray drift [%] as ground sediment to the application rate.

Drift values for biocide applications are based on the 90th percentile of the measured data, in line with the assessment of plant protection products. Ganzelmeier et al. (1995) still used the 95th percentile in the early days of basic drift values. German authorities involved in the authorisation of plant protection products have agreed to use the 90th percentile instead of the 95th percentile, which corresponds to the proposals of the FOCUS Group Surface Waters (Maund, 1999; FOCUS, 2001).

Deviating from these specifications, the maximum values rather than the 90th percentile were used to calculate the basic drift values for a solitary tree. As described above, drift values have never been measured on a solitary tree, which is why the Petri dishes were arranged in such a way that the entire drift was recorded as far as possible. As a result, very low drift values were measured in a series of measurements even in the close range to the treated area, which meant that the 90th percentile was falsely lower than the true value. To better represent a worst-case scenario, the maximum value for this application area was chosen.

Similarly, the basic drift values had to be optimised when treating a forest edge with a cannon sprayer. To determine a worst case scenario, the forest edge was not treated with the wind direction, but against the wind direction. And this was also reflected in the drift values. Thus, the drift values first increase up to a distance of 20 m and then decrease again. The maximum value of the 90th percentile was therefore used for the distances 5, 10 and 20 m.

Results

Figure 2 shows the recommended basic drift values derived from the measured drift values from the drift trials. It can be seen that for all applications, regardless of the device used,

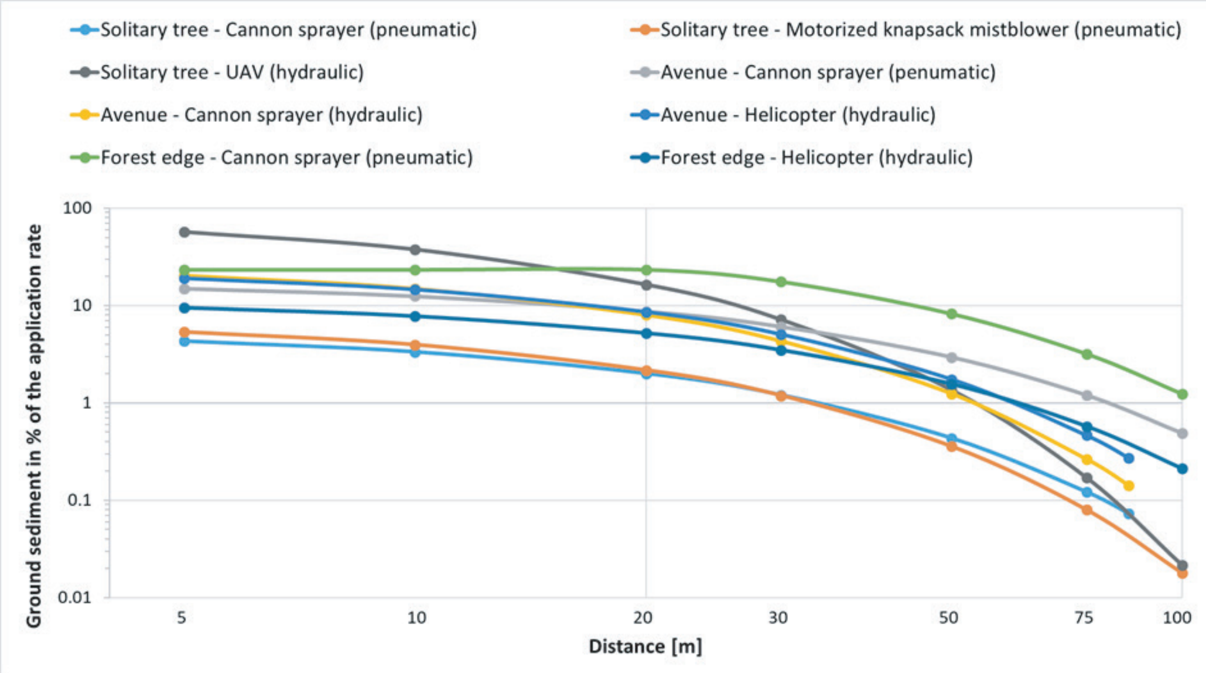

Fig. 2. Recommended basic drift values for the single application of biocidal products in the field for the application areas solitary tree, avenue and forest edge with different devices as ground sediment in % of the application rate (90th percentile).

drift decreases with increasing distance from the treated area. Furthermore, the applications on a solitary tree with a cannon sprayer and a motorised knapsack sprayer show the lowest basic drift values despite the use of the maximum values. Close to the treated area, the application with a UAV on the solitary tree shows the highest basic drift values. At a distance of 100 m from the treated area, the application areas forest edge with cannon sprayer (pneumatic) and avenue with cannon sprayer (pneumatic) show the highest basic drift values.

Discussion

To answer the question posed at the beginning: is it possible to adopt the basic drift values from plant protection for biocides, Figure 3 shows the basic drift values from plant protection. Basic drift values in plant protection are significantly lower in the close range to the treated area and decrease more rapidly with increasing distance. Reasons for the higher values in biocide are the technique, the direction of spraying

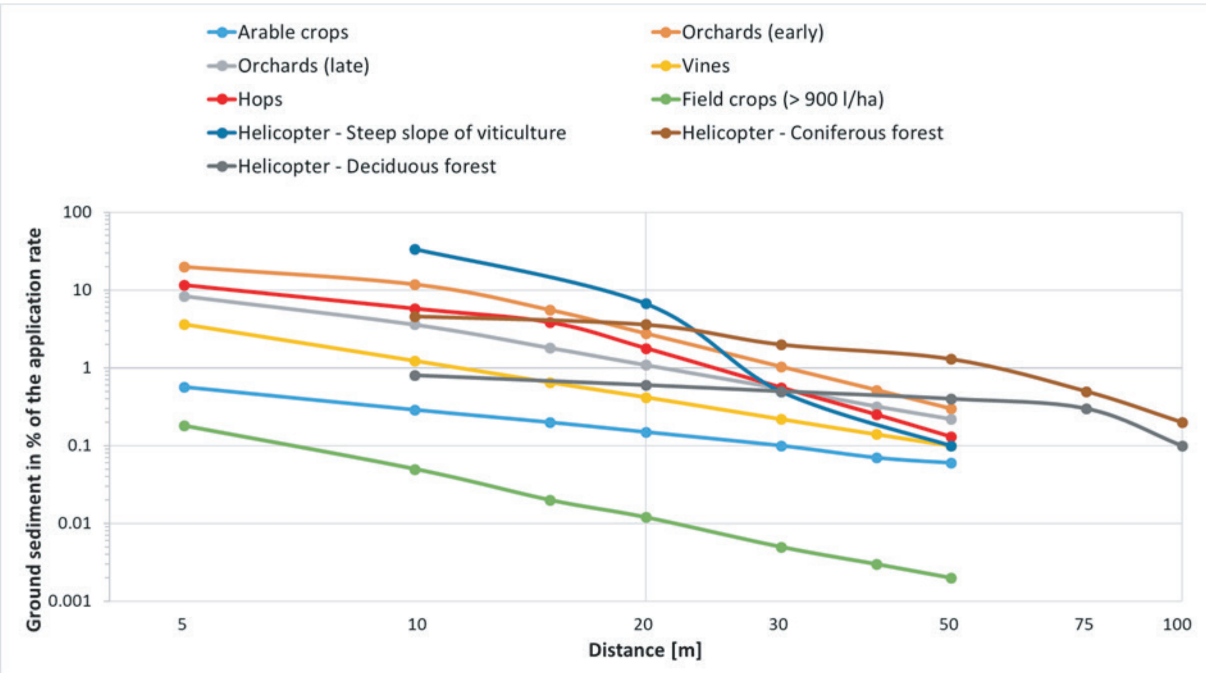

Fig. 3. Recognised basic drift values for the single application of plant protection products in the field (professional applications) as ground sediment in % of the application rate (90th percentile), (JKI, 2022)

and the distance between nozzles and treated area. While in the treatment of arable crops the distance between nozzle and crop is typically around 50 cm, depending on the technique, the distance between a cannon sprayer or a helicopter and a tree crown is several metres (Fig. 4). Similarly, a field sprayer sprays vertically from top to bottom and a cannon sprayer sprays from bottom into the treetop.

For the application of plant protection products with a helicopter in deciduous forest, the basic drift values are significantly lower than for the application of biocides. This is due to the fact that only the forest may be treated when applying plant protection products and not the forest edge. (BMJV, 2012). If the forest edge is treated, it is a biocide measure. The distance between the treated area and the measuring area is therefore greater for a plant protection treatment than for a biocide treatment and the basic drift values are therefore also lower.

Due to the size of the plants, it seems reasonable to assume that the basic drift values are taken from the hops for the control of the oak processionary moth. However, as these drift experiments show, it is not only the crop but also the technique that plays a decisive role. When treating hops, devices with radial blowers are used, which also treat the lower part of the plants and thus produce a different drift behaviour than when using a cannon sprayer.

Conclusion and outlook

A transfer from the area of plant protection therefore proved to be difficult. No application scenario from plant protection corresponded to the scenarios from the biocide area with the devices and application areas mentioned. Due to the topic, it is therefore recommended to define specific basic drift values for each application area and for each device.

At the beginning of 2022, the EU Member States agreed to use the recommended basic drift values in future when assessing applications against the oak processionary moth (ECHA, 2022a). This means that the basic drift values developed in this work are officially recognised and will be taken into account in the risk assessment of biocidal products for oak processionary moth control in future.

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Conflicts of interest

The author(s) declare that they do not have any conflicts of interest.

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Fig. 4. Treatment of an avenue (left) and a forest edge (right) with a cannon sprayer.

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Supplementary information

Table S. Recommended basic drift values derived from the measured drift values for different application areas and devices [%], based on the 90th percentile.

Distance [m]	Solitary tree			Avenue			Forest edge	
	Cannon sprayer (pneumatic)**	Motorized knapsack mistblower from a lifting platform	UAV (hydraulic)	Cannon sprayer (pneumatic)	Cannon sprayer (hydraulic)	Helicopter (hydraulic)	Cannon sprayer (pneumatic)	Helicopter (hydraulic)
5	4.29	5.32	57.00	14.91	20.24	18.98	23.41*	9.43
10	3.32	3.94	37.64	12.45	14.85	14.56	23.41*	7.72
20	2.00	2.16	16.41	8.69	7.99	8.57	23.41*	5.18
30	1.20	1.19	7.16	6.06	4.30	5.04	17.61	3.47
50	0.43	0.36	1.36	2.95	1.24	1.75	8.24	1.56
75	0.12	0.08	0.17	1.20	0.26	0.46	3.19	0.57
85	0.07				0.14	0.27		
100		0.02	0.02	0.49			1.23	0.21

* Maximum value of the 90th percentile is used for the basic drift values.
** Basic drift values are based on the maximum values.

Bundesnaturschutzrecht – Kommentar, Vorschriften und Entscheidungen

Kommentar zum Bundesnaturschutzgesetz (BNatSchG), Vorschriften und Entscheidungen. Prof. Dr. K. Messerschmidt, begründet von Dr. A. Bernatzky † und O. Böhm. Loseblattwerk in 6 Ordnern mit CD-Rom. Heidelberg, rehm, Verlagsgruppe Hüthig Jehle Rehm, ISBN 978-3-8073-2393-0.

162. Aktualisierung, Stand: Dezember 2022

Die Highlights dieser Aktualisierung:

- Überarbeitung der Kommentierung zu § 36, 44 und 67
- Aktualisierung BNatSchG
- 10 neue Entscheidungen

Das bringt Ihnen die 162. Aktualisierung:

Mit der vorliegenden Aktualisierung wird der Kommentarteil hinsichtlich der §§ 36 (Pläne), 44 (Vorschriften für besonders geschützte und bestimmte andere Tier- und Pflanzenarten) und 67 (Befreiungen) auf den neuesten Stand gebracht. Hier steht die Einarbeitung der jüngsten Rechtsprechung im Vordergrund. Das Vierte Gesetz zur Änderung des Bundesnaturschutzgesetzes vom 20. Juli 2022 (BGBI I S. 1362), das eine Ergänzung des § 26 um einen neuen Absatz 3 und die neuen §§ 45b, 45c und 45d gebracht hat, überwiegend zum 29. Juli 2022 in Kraft getreten ist und ganz im Zeichen der Förderung der Windenergieanlagen steht, wird in der Kommentierung rasch folgen. Soweit § 45b die Anwendung des unveränderten § 44 beeinflusst, wurden einige Passagen zu § 44 bis zur nächsten Nachlieferung zurückgestellt.

Daneben wird das BNatSchG aktualisiert.

Außerdem werden 10 neue Entscheidungen aufgenommen.

Die Redaktion

Bundesnaturschutzrecht – Kommentar, Vorschriften und Entscheidungen

Kommentar zum Bundesnaturschutzgesetz (BNatSchG), Vorschriften und Entscheidungen. Prof. Dr. K. Messerschmidt, begründet von Dr. A. Bernatzky † und O. Böhm. Loseblattwerk in 6 Ordnern mit CD-Rom. Heidelberg, rehm, Verlagsgruppe Hüthig Jehle Rehm, ISBN 978-3-8073-2393-0.

163. Aktualisierung, Stand: Februar 2023

Die Highlights dieser Aktualisierung:

- Überarbeitung der Kommentierung § 34
- Aktualisierung BauGB
- 6 neue Entscheidungen

Das bringt Ihnen die 163. Aktualisierung:

Mit dieser Aktualisierung wird § 35 (Verträglichkeit und Unzulässigkeit von Projekten; Ausnahmen) überarbeitet unter Berücksichtigung der aktuellen Gesetzgebung und Rechtsprechung.

Daneben wird das BauGB aktualisiert.

Außerdem werden 6 neue Entscheidungen aufgenommen.

Die Redaktion

Juni/June

03.06.2023 | Braunschweig

Zu Gast bei den Pflanzendoktoren: Tag der offenen Tür am JKI

https://www.julius-kuehn.de/veranstaltungen/veranstaltung/news/zu-gast-bei-den-pflanzendoktoren-tag-der-offenen-tuer-am-jki-braunschweig-messeweg/
Veranstalter: JKI

05. – 07.06.2023 | Berlin

sensorFINT conference 2023

https://www.sensorfint.eu/

07.06.2023 | Dahnsdorf

Feldtag Dahnsdorf

https://www.julius-kuehn.de/vf/versuchsflaechen-dahnsdorfkleinmachnow/
Kontakt: Dr. Jürgen Schwarz
E-Mail: juergen.schwarz@julius-kuehn.de

09.06.2023 | Dahnsdorf

Zukunftsdialog Ökologischer Landbau

https://zukunftsdialogoekolandbau.julius-kuehn.de/

13. – 14.06.2023 | Zossen

Arbeitssitzung Fachreferenten Nematologie

https://www.julius-kuehn.de/veranstaltungen/veranstaltung/news/arbeitssitzung-fachreferenten-nematologie/
E-Mail: johannes.hallmann@julius-kuehn.de

17.06.2023 | Berlin

Tag der offenen Tür in Berlin

https://www.julius-kuehn.de/veranstaltungen/veranstaltung/news/tag-der-offenen-tuer-in-berlin/

19. – 23.06.2023 | Rostock

ILC 2023: 16th International Lupin Conference

https://www.julius-kuehn.de/veranstaltungen/veranstaltung/news/ilc-2023-16th-international-lupin-conference/
Kontakt: Brigitte Ruge-Wehling
E-Mail: brigitte.ruge-wehling@julius-kuehn.de

25.06.2023 | Dossenheim

Tag der offenen Tür am JKI-Standort Dossenheim

https://www.julius-kuehn.de/veranstaltungen/veranstaltung/news/tag-der-offenen-tuer-am-jki-standort-dossenheim-1/

August/August

20. – 25.08.2023 | Lyon, France

12TH International Congress of Plant Pathology

https://www.icpp2023.org/

28.08. – 01.09.2023 | Florence

13th EVPMC 2023 meeting in Florence

https://evpmc2023.co
E-Mail: evpmc2023@gmail.com

September/September

11. – 16.09.2023 | Dresden-Pillnitz

XVI Eucarpia Symposium on Fruit Breeding and Genetics

https://eucarpia-fruit2023.julius-kuehn.de/
Veranstalter: JKI, EUCARPIA, ISHS
E-Mail: henryk.flachowsky@julius-kuehn.de

20. – 22.09.2023 | Berlin

Tropentag

https://www.tropentag.de/
E-Mail: info@tropentag.de

25.09.2023 | Göttingen

Urbane Pflanzen Conferenzen
Wir gestelten die Stadt der Zukunft
Wurzeln und Wasser: Gesunde Pflanzen in der Schwammstadt
VIII. Tagung „Wie funktioniert Stadtgrün besser?“

https://plant-protection.net/de/upc/
Kontakt: Feldmann, Falko
E-Mail: falko.feldmann@julius-kuehn.de

26. – 29.09.2023 | Göttingen

Pflanzenschutztagung

https://www.pflanzenschutztagung.de/
Veranstalter: Julius Kühn-Institut, Bundesforschungsinstitut für Kulturpflanzen
Deutsche Phytomedizinische Gesellschaft e. V.
Landwirtschaftskammer Niedersachsen, Pflanzenschutzamt
E-Mail: info@pflanzenschutztagung.de

Oktober/October

04. – 06.10.2023 | Göttingen

Tagung der Gesellschaft für Pflanzenbauwissenschaften

https://www.gpw.uni-kiel.de/de
Kontakt: Reinhard Neugschwandtner
E-Mail: geschaeftsfuehrer.gpw@boku.ac.at

November/November

12. – 18.11.2023 | Hannover

HOME OF FARMING PIONEERS
Leitthema „Green Productivity“

https://www.agritechnica.com/de/

Dezember/December

04. – 05.12.2023 | Fulda

Resistenztagung 2023
Krankheitsbekämpfung und Resistenzzüchtung in Getreide, Hülsenfrüchten und Raps

https://plant-protection.net/de/resistenztagung

2024

Januar/January

29. – 30.01.2024 | Braunschweig

37. Tagung des DPG-Arbeitskreises Krankheiten in Getreide und Mais

https://www.julius-kuehn.de/veranstaltungen/veranstaltung/news/37-tagung-des-dpg-arbeitskreises-krankheiten-in-getreide-und-mais/
Kontakt: Bernd Rodemann
E-Mail: bernd.rodemann@julius-kuehn.de

30.01.2024 | Braunschweig

18. Treffen des Fachausschusses Pflanzenschutzmittelresistenz – Fungizide

https://www.julius-kuehn.de/veranstaltungen/veranstaltung/news/18-treffen-des-fachausschusses-pflanzenschutzmittelresistenz-fungizide/

Februar/February

27. – 29.02.2024 | Braunschweig

Unkrauttagung
31. Deutsche Arbeitsbesprechung über Fragen der Unkrautbiologie und -bekämpfung

https://www.unkrauttagung.de/
E-Mail: unkrauttagung@julius-kuehn.de

Save the date:
das Julius Kühn-Institut öffnet seine Türen

in Berlin

in Dossenheim

am 25.06.2023 | 10:00 - 16:00 Uhr | Ort: Schwabenheimerstr. 101, 69221 Dossenheim

in Dahnsdorf

am 07.06.2023 | 10:00 - 13:00 Uhr | Ort: Versuchsfeld Dahnsdorf, 14806 Dahnsdorf

https://www.julius-kuehn.de/veranstaltungen/

Journal für Kulturpflanzen

Journal of Cultivated Plants

Inhalt: Band 75 (05-06). S. 129–172, 2023, ISSN 1867-0911
Themenheft: „Spray drift and exposition“

Unser Titelbild:
Freilandversuche zur Messung der Exposition von Abdrift auf Nebenstehende und Anwohner in einer Versuchs-Obstanlage in Braunschweig. Statt Pflanzenschutzmittel wird Wasser mit einem fluoreszierendem Farbstoff appliziert. Auf dem Messfeld neben der Obstplantage werden mit Overalls bekleidete Puppen aufgestellt und der Farbstoffgehalt auf den verschiedenen Körperteilen kann gemessen werden.
Foto: Andreas Herbst (JKI, Braunschweig).

Online Version: https://ojs.openagrar.de/index.php/Kulturpflanzenjournal/index