TEXTE
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Reduction of environmental impact of biocides

Practical study of drift of biocide application equipment and development of drift mitigation measures

by:

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Abstract: Reduction of environmental impact of biocides

On behalf of the German Environment Agency, the Julius Kühn-Institute carried out large-scale drift measurements of biocide applications with a high drift potential to evaluate the environmental impact and potential risk mitigation in more detail. These applications include, for example, the control of the oak processionary moth, the control of flying and crawling insects and the removal of algae on terraces and paths. To measure drift during oak processionary moth control, studies in a previous and this project were conducted at different application areas, such as solitary tree, avenue and forest edge, and with different equipment, such as cannon sprayer, helicopter and UAV. The result was a list of recommended drift values. Initial investigations were carried out with a knapsack sprayer on a house wall and on a paved path to measure drift during the control of flying and crawling insects and during the removal of algae. Based on all results of the drift measurements, recommendations are given on values for the exposure assessment and drift mitigation of the respective products. These measures include the change from cannon sprayer with pneumatic atomisation to cannon sprayer with hydraulic atomisation with drift-reducing nozzles of the latest generation or the change from hollow cone nozzles to flat spray nozzles when using knapsack sprayers. The results of the run-off trials also showed that the recommended spray rates might result in significant losses of up to 50% that could easily be minimized by indicating appropriate application volumes during vertical application. The excursus at the end of the report includes a literature review of ultra-low volume devices that can be used for mosquito control, showing the differences to ULV equipment used in plant protection.

Kurzbeschreibung: Verringerung der Umweltauswirkungen von Bioziden

Im Auftrag des Umweltbundesamts führte das Julius Kühn-Institut großangelegte Messungen zur Abdrift von Biozidanwendungen mit hohem Abdriftpotential durch, um die Auswirkungen auf die Umwelt und mögliche Risikominderungsmaßnahmen zu evaluieren. Zu diesen Anwendungen gehören beispielsweise die Bekämpfung des Eichenprozessionsspinners, die Bekämpfung von fliegenden und kriechenden Insekten und die Entfernung von Algen auf Terrassen und Wegen. Zur Messung der Abdrift bei der Bekämpfung des Eichenprozessionsspinners wurden in einem vorhergehenden und diesem Projekt in verschiedenen Anwendungsbereichen, wie Einzelbaum, Allee und Waldrand, und mit verschiedenen Geräten, wie Sprühkanone, Hubschrauber und UAV, Untersuchungen durchgeführt. Heraus kam eine Liste von empfohlenen Abdrifteckwerten. Zur Messung der Abdrift bei der Bekämpfung von fliegenden und kriechenden Insekten und bei der Entfernung von Algen wurden erste Untersuchungen mit einer Rückenspritze an einer Hauswand und auf einem gepflasterten Weg durchgeführt. Basierend auf allen Ergebnissen werden Empfehlungen zur Expositionsbewertung und möglichen Maßnahmen zur Driftreduktion gegeben. Diese beinhalten einen Wechsel von Sprühkanonen mit pneumatischer Zerstäubung zu Sprühkanonen mit hydraulischen Zerstäubung mit drift-reduzierenden modernen Düsen oder den Wechsel von Hohlkegeldüsen zu Flachstrahldüsen bei der Verwendung von Rückenspritzen. Die Ergebnisse der Versuche zum Run-off zeigten zudem hohe Verluste von bis zu 50%, die minimiert werden könnten, indem bei vertikaler Applikation angemessene Aufwandmengen empfohlen werden. Der Exkurs am Ende des Berichts enthält eine Literaturrecherche mit Geräten, die zur Moskitobekämpfung eingesetzt werde können. Diese Recherche zeigt die Unterschiede zwischen Geräten zur Vektorbekämpfung und Geräten zum Einsatz von Pflanzenschutzmitteln.

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ASABE	American Society of Agricultural and Biological Engineers
BBA	Federal Biological Research Centre for Agriculture and Forestry
BCPC	British Crop Protection Council
DIX	Drift-Potential-Index
ESD	Emission Scenario Document
ISO	International Organization for Standardization
JKI	Julius Kühn-Institute
OECD	Organisation for Economic Co-operation and Development
OPM	Oak Processionary Moth
UAV	Unmanned Aerial Vehicle
ULV	Ultra-low volume

Summary

Parts of this summary have already been published in "Basic drift values in the authorisation procedure for biocidal products (PT18)" (Langkamp-Wedde 2023).

Introduction

Biocidal products are pesticides that are used to protect people, animals and materials from vermin, pests and harmful organisms (EU 2012). Due to their diverse nature, many people are, unconsciously or consciously, using biocidal products, i.e. as insect spray, facade protection, wood stain or disinfectant. As biocidal products are designed to affect organisms, environmental impacts might occur. The Biocidal Products Regulation (EU 528/2012) coordinates the placing on the market and use of biocidal products. One of the aims 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). Lack of knowledge about how some biocidal products are used exactly in the different product types hinders specific exposure assessments and risk mitigation measures.

The application field of biocidal products is very diverse. Therefore, biocidal products have been divided into 4 main groups and 22 product types, including products for the control of insects, acaricides and agents against other arthropods (PT 18) and for the control of algaecides (PT 2). At first view, there is some overlap with agents used for plant protection purposes with some biocidal products used in the open environment, like algaecides and some insecticides. However, upon closer examination, there are significant differences between the knowledge of and regulation for plant protection products and biocides. In the field of plant protection, research on drift has been ongoing for 30 years. Basic drift values are based on more than 100 trials for different application areas such as arable crops, orchards, vines and hops. Lists of recognised plant protection nozzles and devices for drift reduction are also maintained. All these data contribute to the risk assessment and management of plant protection products. However, when it comes to the application of biocides, there is little detailed knowledge about how products of product type 2 and 18 are applied in practice, whether and how they reach adjacent environmental compartments and what measures can be taken to reduce drift. Therefore, there is not enough scientific data available for a detailed assessment of the application phase of biocidal products. The Julius Kühn Institute (JKI), Institute for Application Technology in Plant Protection, has been commissioned by the German Environment Agency to close these knowledge gaps due to existing expertise in the field of drift measurement. The main tasks of this research project and a predecessor project (project no. (FKZ) 3716 67 404 0) were: Identification of applications with high drift potential, measurement of drift in the application of biocides, calculation of basic drift values for the risk assessment of biocidal active substances and products, and development of drift mitigation measures for risk management and sustainable use of biocides.

Literature and market research indicate that the control of Oak Processionary Moth (OPM) control represents an application with high drift potential, followed by control of flying and crawling insects and removal of algae. However, challenging for the assessment of environmental exposure is the fact that the control of OPM 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. Depending on the application area, different devices can be used. To control flying and crawling insects and to removal algae a knapsack sprayer or other pressure sprayers are often used.

Material and Method

In the previous project (project no. (FKZ) 3716 67 404 0) and in the current project, drift was measured during OPM control. A solitary tree was treated with a cannon sprayer with pneumatic atomisation, with a UAV with AirMix 110-05 nozzles and with a motorised knapsack sprayer with pneumatic atomisation. An avenue was treated during with a helicopter with an attached simplex system and with a cannon sprayer with pneumatic and hydraulic atomisation. A forest edge was treated with a cannon sprayer with pneumatic atomisation and with a helicopter with simplex system. For the treatment of a house wall for the control of flying and crawling insects as well as for the removal of algae, the drift was measured during the treatment with a knapsack sprayer and two different nozzles.

For the biocide sector, there is currently no guideline according to which drift tests should be carried out. Therefore, the JKI guideline 7.1-5 "Measuring of direct drift when applying plant protection products outdoors" (JKI 2013b) was used. The application areas 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 collectores were placed in a V-shape on the downwind side in order to capture a large part of the total drift.

For drift measurements for the control of flying and crawling insects on a house wall there is no guideline so far. In extensive preliminary tests, a method was developed in which the drift is measured at a distance of up to 180 cm from the treated surface. The trial area "container" is the side of an overseas container, which is 7.55 meters long and 2.45 meters high, covered with textured plexiglass panels to simulate the structure of a house wall. For flying insect control, the entire wall was treated; for crawling insect control, a foundation was sprayed at a height of 50 cm. Petri dishes used as collectors had a diameter of 145 mm and were placed close together. 10 collectors per row were used and placed in 8 rows. To measure the influence of the wind direction, the trials were carried out at three wind directions: parallel wind direction to the side wall (WSW), orthogonal wind direction (SSE) and wind shadow of the container (NNW).

In addition to drift, the runoff was also measured, which occurs during the treatment of a vertical surface. For this purpose, a V-shaped metal profile was positioned under the plexiglass panel. A fleece was placed in one side of the profile to catch the run-off. A 75 cm wide strip was treated. After application, the fleece was carefully rolled up and transferred to wide-mouth glasses.

For measuring drift during the treatment of a paved path for the removal of algae, an 8-metre-long and one-metre-wide paved path was treated. Next to the paved path, 10 Petri dishes as collectors with a diameter of 145 cm were placed close together every 50 cm. The user walked backwards and treated the paved path at right angles to the direction of movement.

In all trials, water with Pyranine (CAS Number 6358-69-6) as tracer dye was the spray liquid. After each treatment, the collectors were closed and immediately protected from light. In addition, collectors were set up outside the measuring area to determine the blank value. 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 deionised water. For this purpose, 40 mL of deionised water was filled into the collectors and shaken on a shaking table. The frequency and amplitude were chosen so that the inner walls of the collectors were completely washed around. A fluorometer was used to analysis of Pyranine concentration in the wash water of the collectors. Depending on the calibration curve, the volume of the wash fluid, the area of the collectors and the tracer rate, drift was calculated as ground sediment.

Drift values for biocide applications are based on the 90th percentile of the measured data, in line with the assessment of plant protection products. 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 collectors 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 adapted 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

The measurement of drift during OPM control showed, that regardless of the equipment used, drift decreased with increasing distance from the treated area. Specifically, applications to a solitary tree with a cannon sprayer and a motorised backpack sprayer showed the lowest drift values, even though the maximum values were used for the calculation. Close to the treated area, the application with a UAV on a solitary tree showed the highest drift values. It should be noted that the UAV was manually operated. When treating an avenue, the highest drift values were found with a cannon sprayer with pneumatic atomisation and with a cannon sprayer with hydraulic atomization, as well as with a helicopter, both equipped with AirMix 110-05 nozzles. The lowest drift values were observed with a cannon sprayer with hydraulic atomisation and a helicopter, both equipped with ID-120-05 POM nozzles. In fact, a drift mitigation of up to 75% was observed when using a cannon sprayer with ID-120-05 POM nozzles instead of a cannon sprayer with pneumatic atomisation. At a forest edge, the highest drift values were also observed with a cannon sprayer with pneumatic atomization, while the lowest drift values were observed with a helicopter with ID-120-05 POM nozzles. Here, too, the drift mitigation was 75% and at a distance of 10 m from the treated area, the drift mitigation was 90% compared to the cannon spray with pneumatic atomisation.

When treating a house foundation of 50 cm to control crawling insects, the highest drift values were observed with parallel wind direction and with a treatment in the shadow of the wind. The lowest drift values were observed with orthogonal wind direction. Although the IDK 90-015 C nozzle showed the lowest drift values at all three wind directions compared to the standard brass nozzle of the backpack sprayer for all three wind directions, this difference was not significant, and no drift reduction could be observed. When treating an entire house wall to control flying insects, the highest drift values were also observed with parallel wind direction and with treatment in the wind shadow, and the lowest drift values with orthogonal wind direction. In orthogonal and parallel wind directions, higher drift values were observed at near distance with the IDK 90-015 C nozzle than with the brass nozzle. Since the IDK 90-015 C nozzle has larger droplets than the brass nozzle, these fall to the ground more quickly at near distances. The fine drops of the brass nozzle drift further than the drops of the IDK 90-015 C nozzle and therefore the drift of the IDK 90-015 C nozzle decreases faster than that of the brass nozzle. Consequently, at a distance of 99 cm from the treated area, a drift reduction of 50% for the IDK 90-015 C nozzle compared to the brass nozzle could be observed.

The measurement the runoff on a vertical surface clearly showed the influence of the application rate. At an application rate of 112 mL m^{-2}, as recommended for some products, 50% of the spread rate was recovered. When the application rate was 53 mL $m^{-2,}$ the runoff was 0.5% of the spread rate. No difference was found between the brass nozzle and the IDK 90-015 C nozzle.

When measuring the drift during the treatment of a paved path, the highest drift values were observed with the brass nozzle, and the lowest drift values with the IDK 90-015 C nozzle. A drift mitigation of 75% and, at a distance of 43 cm from the treated area, a drift mitigation of 90% of the IDK 90-015 C nozzle compared to the brass nozzle could be observed.

Discussion

When comparing biocidal products and plant protection products, the basic drift values from plant protection products are significantly lower in the close range to the treated area and decrease more rapidly with increasing distance. Reasons for the higher values in the application of biocides include the technology used, the application direction and the distance between nozzles and treated area. While the distance between the nozzle and target area is typically around 50 cm in the treatment of crops, the distance between a cannon sprayer or a helicopter and a tree crown is several meters. Similarly, a field sprayer sprays vertically from top to bottom, while a cannon sprayer sprays from bottom to top into the tree crown. 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 at a forest edge. This is due to the fact that only the forest may be treated when applying plant protection products and not the forest edge. (BMJ 2012). Therefore, the distance between the treated area and the measuring area is greater for a plant protection treatment than in biocide treatment, resulting in lower drift values. Due to the size of the oaks in comparison to hops, it was previously assumed that the drift values for the control of the OPM from hops could be adopted. However, as these drift experiments show, it is not only the crop but also the technology plays a decisive role. When treating hops, devices with radial blowers are used, which also treat the lower part of the plants showing a different drift behavior than when using a spray cannon that only treats the upper part of the plants. Therefore, transferring basic drift values from plant protection proved to be difficult. No application scenario from plant protection corresponded to the scenarios from the biocide sector with the mentioned devices and application areas. It is, therefore, recommended to define specific basic drift values for each application area and for each device in the biocidal sector. In addition, a change from cannon sprayers with pneumatic atomisation to cannon sprayers with hydraulic atomisation is recommended as a possible drift reduction measure for the exposure assessment.

For the control of flying and crawling insects on a house wall, no drift values are available. In their Emission Scenario Document (ESD) for insecticides, acaricides and other arthropod control products for residential and commercial areas, the OECD provides only a default value of 10% for fractions deposited on the ground during spray application. For crawling insect control, the default value of 10% was undercut at a distance of 57 cm for all three wind directions and with both nozzles in the experiments. When treating an entire house wall, default value was no undercut for the first 100 cm. However, it is unclear what proportion is caused by drift and what proportion is caused by rebound. Additionally, the extent to which rebound affects the overall deposition is not clarified. Laboratory tests of the nozzles showed that the IDK 90-015 C nozzle produces larger droplets than the brass nozzles. Large droplets have a greater kinetic energy and can therefore rebound more strongly. This is a possible explanation for why higher values were measured at close range in these drift tests with the IDK 90-015 C nozzle than with the brass nozzle. However, considering only one value can lead to significant misunderstandings. It was also found that drift with the IDK 90-015 C nozzle decreased more rapidly than with the brass nozzle, as the brass nozzle produces a higher proportion of fine droplets that can drift much farther. In drift trials and when evaluating nozzles, it is therefore recommended to use at least 5 distances for drift measurement, as considered exposure assessment according to the JKI Guideline 7-1.5, to obtain meaningful and comparable reference values for a risk assessment. Based on the results, a nozzle change from hollow cone nozzles to flat fan nozzles is also recommended for this area of application as a possible drift mitigation measure for the exposure assessment. A recommendation for wind direction cannot be given. Even though the results show that applications with orthogonal wind direction produce the least drift, it is not practical to treat a house only in one wind direction, as rarely is only one side of a house treated.

The results of the run-off trials showed a significant influence of the application rate. High losses of up to 50 % could be minimised if appropriate application rates were recommended for vertical application. Specifications of "1 litre of application solution for 10 to 20 m^2" are not helpful for inexperienced users and, conversely, imply an application rate of 50 to 100 mL m^{-2}. It is therefore recommended to specify the application rate according on the orientation of the application area. Additionally, it is important to consider that the investigations were conducted using an IDK 90-015 C flat fan nozzle. Nozzles with a larger aperture produce larger droplets that can result in even faster run-off.

Excursus

The excursus at the end of the report includes a literature review of ULV (Ultra Low Volume) devices that can be used for vector control. Droplet size plays a crucial role in efficient vector control, with the most successful control achieved with average droplet sizes ranging from 8 to 30 µm in diameter. Smaller droplets remain in the air for longer and thus increase the likelihood of contact with mosquitoes during foraging. Various manufacturers produce portable and non-portable cold and thermal fogging devices to achieve these small droplet sizes. However, comparing these devices with those used for field applications in plant protection is challenging. The aim of avoiding small droplets in the air is contradictory in plant protection. According to §16 of the Plant Protection Act, devices for the application of plant protection products must be designed in such a way that they do not have any harmful effects on human and animal health or on groundwater when used as intended. Therefore, in plant protection, ULV applications are restricted to enclosed spaces such as greenhouses or outdoor areas with devices equipped with additional shielding to ensure that only the target plant is treated and the drift potential is minimised.

Zusammenfassung

Teile dieser Zusammenfassung sind bereits in "Basic drift values in the authorisation procedure for biocidal products (PT18)" (Langkamp-Wedde 2023) veröffentlicht worden.

Einführung

Biozidprodukte sind Pestizide, die verwendet werden, um Menschen, Tiere und Materialien vor Ungeziefer, Schädlingen und schädlichen Organismen zu schützen (EU 2012). Aufgrund ihrer vielfältigen Natur verwenden viele Menschen unbewusst oder bewusst Biozidprodukte, z. B. als Insektenspray, Fassadenschutz, Holzbeize oder Desinfektionsmittel. Da Biozidprodukte darauf ausgelegt sind, Organismen zu beeinflussen, können Umweltauswirkungen auftreten. Die Biozid-Produkte-Verordnung (EU 528/2012) koordiniert das Inverkehrbringen und die Verwendung von Biozidprodukten. Eines der Ziele dieser Verordnung ist die Identifizierung möglicher Risiken, die sich aus der Verwendung von Biozidprodukten für die menschliche und tierische Gesundheit oder die Umwelt ergeben können und die Ableitung geeigneter Maßnahmen zur Sicherstellung einer sicheren Verwendung von Biozidprodukten (EU 2012). Ein Mangel an Wissen darüber, wie einige Biozidprodukte genau in den verschiedenen Produkttypen verwendet werden, erschwert spezifische Expositionsabschätzungen und die Ableitung von Risikominderungsmaßnahmen.

Das Anwendungsgebiet von Biozidprodukten ist sehr vielfältig. Daher werden Biozidprodukte in 4 Hauptgruppen und 22 Produkttypen eingeteilt, darunter Produkte zur Bekämpfung von Insekten, Akariziden und Mitteln gegen andere Arthropoden (PT 18) und von Algiziden (PT 2). Auf den ersten Blick gibt es einige Überschneidungen mit Mitteln, die für den Pflanzenschutz verwendet werden, mit einigen Biozidprodukten, die in der offenen Umgebung verwendet werden, wie Algizide und einige Insektizide. Bei genauerer Betrachtung gibt es jedoch erhebliche Unterschiede im dem Wissen über und in der Regulierung von Pflanzenschutzmitteln und Bioziden. Im Bereich des Pflanzenschutzes wird seit 30 Jahren an der Erforschung der Abdrift gearbeitet. Die Abdrifteckwerte basieren auf mehr als 100 Versuchen für verschiedene Anwendungsgebiete im Acker-, Obst-, Wein- und Hopfenbau. Auch Listen von anerkannten Pflanzenschutzdüsen und Geräten zur Abdriftminderung werden geführt. All diese Daten tragen zur Risikobewertung und -reduzierung von Pflanzenschutzmitteln bei. Bei der Anwendung von Bioziden besteht jedoch wenig detailliertes Wissen darüber, wie Produkte des Produkttyps 2 und 18 in der Praxis angewendet werden, ob und wie sie angrenzende Umweltkompartimente erreichen und welche Maßnahmen zur Verringerung der Abdrift ergriffen werden können. Daher stehen nicht genügend wissenschaftliche Daten für eine detaillierte Bewertung der Anwendungsphase von Biozidprodukten zur Verfügung. Das Julius Kühn-Institut (JKI), Institut für Anwendungstechnik im Pflanzenschutz, wurde daher vom deutschen Umweltbundesamt beauftragt, diese Wissenslücken aufgrund der bestehenden Expertise im Bereich der Abdriftmessung zu schließen. Die Hauptaufgaben dieses Forschungsprojekts und eines Vorgängerprojekts (Projektnummer (FKZ) 3716 67 404 0) waren: Identifizierung von Anwendungen mit hohem Abdriftpotential, Messung der Abdrift bei der Anwendung von Bioziden, Berechnung von Abdrifteckwerten für die Risikobewertung von bioziden Wirkstoffen und Produkten und Entwicklung von Adriftminderungsmaßnahmen für das Risikomanagement und die nachhaltige Verwendung von Bioziden.

Literatur- und Marktforschungen zeigen, dass die Kontrolle des Eichenprozessionsspinners (EPS) eine Anwendung mit hohem Abdriftpotential darstellt, gefolgt von der Kontrolle fliegender und kriechender Insekten und der Entfernung von Algen. Herausfordernd für die Beurteilung der Umweltexposition ist jedoch, dass die Kontrolle des Eichenprozessionsspinners nicht nur ein System umfasst, sondern eine Vielzahl von Geräten mit unterschiedlichen

Sprühsystemen und Arten der Zerstäubung eingesetzt werden. Sprühkanonen mit pneumatischer oder hydraulischer Zerstäubung, Hubschrauber mit angebrachten Simplex-Systemen, unbemannte Luftfahrzeuge mit Sprühausrüstung oder motorisierte Rückensprühgeräte mit pneumatischer Zerstäubung von einer Hebebühne aus können hierfür verwendet werden. Der Grund für diese große Vielfalt an Geräten ist die breite Variation des Anwendungsgebietes. So wurden EPS sowohl an Einzelbäumen als auch an Eichenalleen oder Waldrändern beobachtet und müssen dort bekämpft werden, um die Öffentlichkeit zu schützen. Je nach Anwendungsgebiet können also unterschiedliche Geräte eingesetzt werden. Zur Bekämpfung fliegender und kriechender Insekten und zur Entfernung von Algen werden häufig Handsprühgeräte oder andere Drucksprühgeräte verwendet.

Material und Methode

Im vorherigen Projekt (Projektnummer (FKZ) 3716 67 404 0) und im vorliegenden Projekt wurde die Abdrift bei der Kontrolle von EPS gemessen, wenn ein Einzelbaum mit einer Sprühkanonen mit pneumatischer Zerstäubung, mit einem UAV mit AirMix 110-05 Düsen und mit einem motorisierten Rückensprühgerät mit pneumatischer Zerstäubung behandelt wurde. Bei einer Allee wurde die Abdrift bei der Behandlung mit einem Hubschrauber mit angebrachtem Simplex-System und mit Sprühkanonen mit pneumatischer und hydraulischer Zerstäubung gemessen. Die Abdrift am Waldrand wurde mit einer Sprühkanone mit pneumatischer Zerstäubung und mit einem Hubschrauber mit Simplex-System gemessen. Für die Behandlung einer Hauswand zur Bekämpfung von fliegenden und kriechenden Insekten sowie zur Entfernung von Algen wurde die Abdrift während der Behandlung mit einer Rückenspritze mit zwei verschiedenen Düsen gemessen.

Für den Biozidbereich gibt es derzeit keine Richtlinie, nach der Abdriftversuche durchgeführt werden sollten. Daher wurde die JKI-Richtlinie 7.1-5 "Messung der direkten Abdrift bei der Anwendung von Pflanzenschutzmitteln im Freiland" (JKI 2013b) herangezogen. Die Anwendungsgebiete wurden in behandelte Fläche und Messfläche unterteilt. Die Messfläche befindet sich neben der behandelten Fläche auf der windabgewandten Seite. Petrischalen mit einem Durchmesser von 145 mm dienten als Kollektoren und sammelten die Abdrift als Bodensediment auf. Dafür wurden die Kollektoren auf Holzlatten in der Messfläche verteilt. Gemäß JKI-Richtlinie 7-1.5 werden die Kollektoren so verteilt, dass ein repräsentativer Abschnitt der gesamten Drift erfasst wird. Die Messabstände zum Kronenrand der behandelten Fläche betrugen 5, 10, 20, 30, 50, 75 und 85 oder 100 m, je nach Größe der Messfläche. In jedem Messabstand wurden 10 Kollektoren in einem Abstand von 2 m voneinander aufgestellt. Da die Abdrift von der Behandlung eines Einzelbaums noch nie gemessen wurde, wurde die Richtlinie hier leicht angepasst. In diesem Fall wurden die Petrischalen in V-Form auf der windabgewandten Seite platziert, um einen großen Teil der Gesamtabdrift zu erfassen.

Für Abdriftmessungen zur Kontrolle fliegender und kriechender Insekten an einer Hauswand gibt es bisher ebenfalls keine Richtlinie. In umfangreichen Vorversuchen wurde eine Methode entwickelt, bei der die Abdrift in einer Entfernung von bis zu 180 cm von der behandelten Oberfläche gemessen wird. Als Versuchsfläche dient die Seitenwand eines Überseecontainers. Diese ist 7,55 m lang und 2,45 m hoch und wurde mit geriffelten Plexiglasplatten bedeckt, um die Struktur einer Hauswand zu simulieren. Für die Bekämpfung fliegender Insekten wurde die gesamte Wand behandelt; für die Bekämpfung kriechender Insekten wurde eine Fundamentapplikation in einer Höhe von 50 cm durchgeführt. Die als Kollektoren verwendeten Petrischalen hatten einen Durchmesser von 145 mm und wurden eng beieinander platziert. Es wurden 10 Kollektoren pro Reihe verwendet und in 8 Reihen platziert. Um den Einfluss der Windrichtung zu messen, wurden die Versuche bei drei Windrichtungen durchgeführt: parallele

Windrichtung zur Seitenwand (WSW), orthogonale Windrichtung (SSO) und Windschatten des Containers (NNW).

Neben der Abdrift wurde auch der Abfluss gemessen, der bei der Behandlung einer vertikalen Oberfläche entsteht. Hierfür wurde ein V-förmiges Metallprofil unter der Plexiglasplatte positioniert. Ein Vlies wurde auf einer Seite des Profils platziert, um den Abfluss aufzufangen. Nach der Anwendung wurde das Vlies sorgfältig aufgerollt und in Weithalsgläser überführt.

Für die Messung der Abdrift während der Behandlung eines Weges zur Entfernung von Algen wurde ein 8 Meter langer und ein Meter breiter Weg behandelt. Neben dem Weg wurden 10 Petrischalen mit einem Durchmesser von 145 cm als Kollektoren alle 50 cm eng beieinander platziert. Der Anwender ging rückwärts und behandelte den Weg im rechten Winkel zur Laufrichtung.

Bei allen Versuchen wurde als Sprühflüssigkeit Wasser mit Pyranin (CAS-Nummer 6358-69-6) als Tracer-Farbstoff verwendet. Nach jeder Behandlung wurden die Kollektoren geschlossen und sofort vor Licht geschützt. Darüber hinaus wurden Kollektoren außerhalb der Messfläche aufgestellt, um den Nullwert zu bestimmen. Während der Versuche wurden Tankproben entnommen, um die Aufwandmenge zu überprüfen und festzustellen, ob die Tracer-Konzentration in der Spritzflüssigkeit während der Anwendung stabil blieb. Für die Analyse wurde der Tracer aus den Kollektoren mit deionisiertem Wasser extrahiert. Hierfür wurden 40 mL deionisiertes Wasser in die Kollektoren gefüllt und auf einem Schütteltisch geschüttelt. Die Frequenz und die Amplitude wurden so gewählt, dass die Innenwände der Kollektoren vollständig umspült wurden. Für die Analyse der Pyranin-Konzentration im Spülwasser der Kollektoren wurde ein Fluorometer verwendet. Abhängig von der Kalibrierungskurve, dem Volumen der Spühlflüssigkeit, der Fläche der Kollektoren und der Tracerrate wurde die Abdrift als Bodensediment berechnet.

Die Abdrifteckwerte für Biozidanwendungen basieren auf dem 90. Perzentil der gemessenen Daten, in Übereinstimmung mit der Bewertung von Pflanzenschutzmitteln. Abweichend von diesen Spezifikationen wurden zur Berechnung der Abdrifteckwerte für einen Einzelbaum die Maximalwerte anstelle des 90. Perzentils verwendet. Wie oben beschrieben, wurde die Abdrift noch nie an einem Einzelbaum gemessen, weshalb die Kollektoren so angeordnet waren, dass die gesamte Abdrift so weit wie möglich erfasst wurde. Infolgedessen wurden selbst in unmittelbarer Nähe zum behandelten Bereich sehr niedrige Abdriftwerte gemessen, was bedeutete, dass das 90. Perzentil fälschlicherweise niedriger als der tatsächliche Wert war. Um ein Worst-Case-Szenario besser darzustellen, wurde der Maximalwert für diesen Anwendungsbereich gewählt. Ebenso mussten die Abdrifteckwerte bei der Behandlung eines Waldrandes mit einer Sprühkanone angepasst werden. Um ein Worst-Case-Szenario zu ermitteln, wurde der Waldrand nicht mit der Windrichtung, sondern gegen die Windrichtung behandelt, und dies spiegelte sich auch in den Abdriftwerten wider. Diese steigen zunächst bis zu einer Entfernung von 20 m an und nehmen dann wieder ab. Der Maximalwert des 90. Perzentils wurde daher für die Entfernungen 5, 10 und 20 m verwendet.

Ergebnisse

Die Messung der Abdrift bei der Bekämpfung von EPS zeigte, dass unabhängig von der verwendeten Technik die Abdrift mit zunehmender Entfernung vom behandelten Bereich abnimmt. Speziell zeigten Anwendungen an einem Einzelbaum mit einer Sprühkanone und einem motorisierten Rückensprühgerät die niedrigsten Abdriftwerte, obwohl die Maximalwerte für diese Berechnung verwendet wurden. Im Nahbereich der behandelten Fläche zeigten Anwendungen mit einem UAV an einem Einzelbaum die höchsten Abdriftwerte. Zu beachten ist, dass das UAV manuell geflogen wurde. Bei der Behandlung einer Allee wurden die höchsten

Abdriftwerte mit einer Sprühkanone mit pneumatischer Zerstäubung und mit einer Sprühkanone mit hydraulischer Zerstäubung und einem Hubschrauber, beide ausgestattet mit AirMix 110-05 Düsen, festgestellt. Die niedrigsten Abdriftwerte wurden mit einer Sprühkanone mit hydraulischer Zerstäubung und einem Hubschrauber, beide ausgestattet mit ID-120-05 POM Düsen, beobachtet. Tatsächlich wurde eine Abdriftminderung von bis zu 75% festgestellt, wenn anstelle einer Sprühkanone mit pneumatischer Zerstäubung eine Sprühkanone mit ID-120-05 POM Düsen verwendet wurde. An einem Waldrand wurden ebenfalls die höchsten Abdriftwerte mit einer Sprühkanone mit pneumatischer Zerstäubung und die niedrigsten Abdriftwerte mit einem Hubschrauber mit ID-120-05 POM Düsen beobachtet. Auch hier betrug die Abdriftminderung 75% und ab einer Entfernung von 10 m zur behandelten Fläche betrug die Abdriftminderung im Vergleich zur Sprühkanone mit pneumatischer Zerstäubung 90%.

Bei der Behandlung eines Hausfundaments von 50 cm zur Kontrolle von kriechenden Insekten wurden die höchsten Abdriftwerte bei paralleler Windrichtung und bei einer Behandlung im Schatten beobachtet. Die niedrigsten Abdriftwerte wurden bei orthogonaler Windrichtung beobachtet. Obwohl die IDK 90-015 C Düse bei allen drei Windrichtungen die niedrigsten Abdriftwerte im Vergleich zur serienmäßigen Messingdüse der Rückenspritze aufwies, war dieser Unterschied nicht signifikant, und es konnte keine Abdriftminderung beobachtet werden. Bei der Behandlung einer gesamten Hauswand zur Kontrolle von fliegenden Insekten wurden ebenfalls die höchsten Abdriftwerte bei paralleler Windrichtung und bei einer Behandlung im Windschatten und die niedrigsten Abdriftwerte bei orthogonaler Windrichtung beobachtet. Bei orthogonalen und parallelen Windrichtungen wurden bei geringer Entfernung höhere Abdriftwerte mit der IDK 90-015 C Düse als mit der Messingdüse beobachtet. Da die IDK 90-015 C Düse größere Tropfen erzeugt als die Messingdüse, fallen diese Tropfen schneller zu Boden. Die feinen Tropfen der Messingdüse driften weiter als die Tropfen der IDK 90-015 C Düse, und daher nimmt die Abdrift der IDK 90-015 C Düse schneller ab als bei der Messingdüse. Ab einer Entfernung von 99 cm zur behandelten Fläche konnte daher auch eine Abdriftminderung von 50% der IDK 90-015 C Düse zur Messingdüse beobachtet werden.

Die Messung des Abflusses an einer vertikalen Fläche zeigte deutlich den Einfluss der Aufwandmenge. Bei einer Aufwandmenge von 112 mL m^{-2}, wie sie für einige Produkte empfohlen wird, wurde 50% der ausgebrachten Menge wiedergefunden. Wenn die Aufwandmenge 53 mL m^{-2} betrug, betrug der Abfluss 0,5%. Es wurde kein Unterschied zwischen der Messingdüse und der IDK 90-015 C Düse festgestellt.

Bei der Messung der Abdrift bei der Behandlung eines gepflasterten Weges wurden die höchsten Abdriftwerte mit der Messingdüse und die niedrigsten Abdriftwerte mit der IDK 90-015 C Düse beobachtet. Eine Abdriftminderung von 75% und ab einer Entfernung von 43 cm zum behandelten Bereich eine Abdriftminderung von 90% konnte mit der IDK 90-015 C Düse im Vergleich zur Messingdüse beobachtet werden.

Diskussion

Beim Vergleich zwischen Biozidprodukten und Pflanzenschutzmitteln sind die Abdrifteckwerte von Pflanzenschutzmitteln im Nahbereich zur behandelten Fläche signifikant niedriger und nehmen mit zunehmender Entfernung schneller ab. Gründe für die höheren Werte bei der Anwendung von Bioziden sind die eingesetzte Technik, die Applikationsrichtung und der Abstand zwischen Düsen und behandelter Fläche. Während bei der Behandlung von Feldfrüchten der Abstand zwischen Düse und Zielfläche in der Regel etwa 50 cm beträgt, beträgt der Abstand zwischen einer Sprühkanone oder einem Hubschrauber und der Baumkrone mehrere Meter. Ebenso sprüht ein Feldspritzgerät senkrecht von oben nach unten, während eine Sprühkanone von unten nach oben in die Baumkrone sprüht. Für die Anwendung von

Pflanzenschutzmitteln mit einem Hubschrauber im Laubwald sind die Abdrifteckwerte signifikant niedriger als für die Anwendung von Bioziden an einem Waldrand. Dies liegt daran, dass bei der Anwendung von Pflanzenschutzmitteln nur der Wald behandelt werden darf und nicht der Waldrand. (BMJ 2012). Der Abstand zwischen der behandelten Fläche und der Messfläche ist daher bei einer Pflanzenschutzbehandlung größer als bei einer Biozidbehandlung. Die Abdrifteckwerte sind daher auch niedriger. Aufgrund der Größe der Eichen im Vergleich zu Hopfen wurde bisher angenommen, dass die Abdriftwerte für die Bekämpfung des Eichenprozessionsspinners von Hopfen übernommen werden könnten. Wie diese Abdriftversuche jedoch zeigen, spielt nicht nur die Kultur, sondern auch die Technik eine entscheidende Rolle. Bei der Behandlung von Hopfen werden Geräte mit Radialgebläsen verwendet, die auch den unteren Teil der Pflanzen behandeln und somit ein anderes Abdriftverhalten zeigen als bei der Verwendung einer Sprühkanone, die nur den oberen Teil der Pflanzen behandelt. Eine Übertragung von Abdriftwerten aus dem Bereich des Pflanzenschutzes erwies sich daher als schwierig. Kein Anwendungsszenario aus dem Pflanzenschutzbereich entsprach den Szenarien aus dem Biozidbereich mit den genannten Geräten und Anwendungsbereichen. Es wird daher empfohlen, spezifische Abdrifteckwerte für jeden Anwendungsbereich und für jedes Gerät im Biozidbereich zumessen. Zudem wird als mögliche Maßnahme der Abdriftminderung einen Wechsel von Sprühkanonen mit pneumatischer Zerstäubung zu Sprühkanonen mit hydraulischer Zerstäubung empfohlen.

Für die Kontrolle von fliegenden und kriechenden Insekten an einer Hauswand liegen keine Abdriftwerte vor. Die OECD gibt in ihrem Emissions-Szenario-Dokument (ESD) für Insektizide, Akarizide und Produkte zur Kontrolle andere Arthropoden für den Wohn- und Gewerbebereich nur einen Standardwert von 10 % für die auf dem Boden abgelagerten Fraktionen während der Sprühanwendung an. Für die Kontrolle von kriechenden Insekten wurde der Standardwert von 10 % in allen drei Windrichtungen und mit beiden Düsen erst bei einer Entfernung von 57 cm unterschritten. Bei der Behandlung einer gesamten Hauswand wurde der Standardwert auf den ersten 100 cm nicht unterschritten. Es ist jedoch unklar, welcher Anteil durch Abdrift und welcher Anteil durch Rückprall verursacht wird. Zudem ist nicht geklärt, wie weit sich der Rückprall auswirkt. Laboruntersuchungen der Düsen zeigten, dass die IDK 90-015 C Düse größere Tropfen produziert als die Messingdüsen. Große Tropfen haben eine größere kinetische Energie und können somit stärker zurückprallen. Dies ist eine mögliche Erklärung, warum in diesen Abdriftversuchen mit der IDK 90-015 C Düse höhere Werte im Nahbereich gemessen wurden als mit der Messingdüse. Wenn jedoch nur ein Wert berücksichtigt wird, kann dies zu erheblichen Missverständnissen führen. Denn es zeigte sich auch, dass die Abdrift mit der IDK 90-015 C Düse schneller abnahm als mit der Messingdüse, da die Messingdüse einen höheren Anteil an Feintropfen produziert, die wesentlich weiter abdriften können. Bei Abdriftversuchen und bei der Bewertung von Düsen wird daher empfohlen, mindestens 5 Entfernungen zur Messung der Abdrift zu verwenden, wie es auch bei der Expositionsabschätzung gemäß der JKI-Richtlinie 7-1.5 berücksichtigt wird, um aussagekräftige und vergleichbare Referenzwerte für eine Risikobewertung zu erhalten. Basierend auf den Ergebnissen wird auch für diesen Anwendungsbereich als mögliche Maßnahme der Abdriftminderung für die Expositionsbewertung ein Düsenwechsel von Hohlkegeldüsen auf Flachstrahldüsen empfohlen. Eine Empfehlung der Windrichtung kann nicht ausgesprochen werden. Auch wenn die Ergebnisse zeigen, dass Anwendungen bei orthogonaler Windrichtung die geringste Abdrift erzeugen, ist es nicht praxistauglich ein Haus nur bei einer Windrichtung zu behandeln da selten nur eine Hausseite behandelt wird.

Die Ergebnisse der Versuche zum Run-off zeigten einen deutlichen Einfluss der Aufwandmenge. So können hohe Verluste von bis zu 50 % minimiert werden, wenn bei vertikaler Applikation angemessene Aufwandmengen empfohlen werden würden. Angaben von „1 L

Anwendungslösung auf 10 bis 20 m^2“ sind für ungeübte Anwender nicht hilfreich und bedeuten im Umkehrschluss eine Aufwandmenge von 50 bis 100 mL m^{-2}. Es ist daher zu empfehlen die Aufwandmenge nach Ausrichtung der Applikationsfläche anzugeben. Zudem ist bei den Empfehlungen zu beachten, dass die Untersuchungen mit einer IDK 90-015 C Flachstrahldüse durchgeführt wurden. Düsen mit einer größeren Öffnung erzeugen größere Tropfen, die einen noch schnelleren Run-off erzeugen können.

Exkurs

Der Exkurs am Ende des Berichts enthält eine Literaturrecherche mit ULV-Geräten, die zur Vektorkontrolle eingesetzt werde können. Bei der effizienten Vektorkontrolle spielt die Tröpfchengröße eine wichtige Rolle. Die erfolgreichste Bekämpfung gelingt bei durchschnittlichen Tropfengrößen von 8 bis 30 µm Durchmesser. Kleinere Tröpfchen bleiben länger in der Luft und erhöhen so die Wahrscheinlichkeit eines Kontakts mit Mücken bei der Nahrungssuche. Um diese kleinen Tropfengrößen zu erreichen, stellen verschiedene Hersteller tragbare und nicht tragbare Kalt- und Heißnebelgeräte her. Der Vergleich dieser Geräte mit denen für den Feldeinsatz im Pflanzenschutz ist jedoch schwierig. Das Ziel, kleine Tröpfchen in der Luft zu vermeiden, ist im Pflanzenschutz widersprüchlich. Gemäß §16 des Pflanzenschutzgesetzes müssen Geräte zur Ausbringung von Pflanzenschutzmitteln so beschaffen sein, dass sie bei bestimmungsgemäßer Anwendung keine schädlichen Auswirkungen auf die Gesundheit von Mensch und Tier sowie auf das Grundwasser haben. Daher sind ULV-Anwendungen im Pflanzenschutz auf geschlossene Räume wie Gewächshäuser oder Außenbereiche mit Geräten beschränkt, die mit zusätzlichen Abschirmungen ausgestattet sind, um sicherzustellen, dass nur die Zielpflanze behandelt wird und das Abdriftpotenzial minimiert wird.

1 Introduction

This report is the final report of the second project on measuring the drift of devices for the application of biocidal products. The first project started in 2016 under the name "Drift reduction in spray application/fogging of biocides - derivation of risk reduction measures and equipment requirements" (FKZ 3716 67 404 0). Further information on biocidal product types and their potential for direct environmental exposure through drift can be found in its final report by Langkamp-Wedde et al. (2020). The aim of this follow-up project called "Reducing environmental exposure to biocides: Practical study of drift of biocide application equipment and development of drift mitigation measures" (FKZ 3719 67 404 0) is:

- to measure further drift values of different applications in experimental studies to assess environmental exposure
- to compare droplet size of different nozzles and their behaviour with regard to their drift potential
- to compare other parameters such as working pressure and application height and their behaviour with regard to drift potential
- to formulate risk mitigation measures related to drift.

The results of the previous project are also considered in this final report, as all experimental studies are used together to recommend basic drift values and risk reduction measures for the risk assessment of biocidal active substances and products.

1.1 Factors influencing drift

The measurement of drift in experimental studies to investigate the environmental exposure during spraying of chemicals is not new. Between 1989 and 1992, more than 100 drift measurements were carried out in Germany by plant protection product manufacturers and offices of the official plant protection service according to the guidelines of the Federal Biological Research Centre for Agriculture and Forestry (BBA) in an extensive measurement programme (Ganzelmeier et al. 1995). With these scientifically founded measurement results, the unsatisfactory data basis regarding drift of plant protection products at that time was eliminated and basic drift values were developed for the environmental risk assessment in the approval procedure. While the risk assessment of plant protection products on the basis of drift values is a recognised method, the biocides sector is still in its infancy. There are large gaps in knowledge about how biocidal products are applied and the effects of drift on adjacent environmental compartments. Basic drift values of plant protection products cannot be simply transferred to biocidal products as the settings of the applications are too different. What is clear, however, is that the factors influencing drift are identical.

In both the plant protection and biocide sectors, different devices such as knapsack sprayers and mechanised sprayers with different drift characteristics are used. The difficulty with hand-held devices is to maintain a constant spray pressure, a constant spray height and a constant spray angle. Other factors related to care, setting and operator skills play an important role (Franke et al. 2010). According to Franke et al. (2010), the factors that influence drift from plant protection products can be summarised in groups:

- Weather conditions (wind speed, temperature, relative humidity, atmospheric stability).

- Application factors (sprayer type, nozzle type and size, spraying pressure, application height and angle).
- Formulation (additives, density, and viscosity).
- Care, attitude and skill of the operator.

The magnitude of the influence varies greatly. The weather conditions or the user can have a greater influence separately, but also both parameters together in interaction can strongly influence the drift. Details of the factors influencing drift and a comparison of the influence on agricultural field sprayers and knapsack sprayers for the application of plant protection products and biocidal products are described below. However, the influence of the formulation will not be discussed, as there are only few parallels between the applications in plant protection and in biocides and a detailed description of this parameter exceeds the scope and subject of this study. Furthermore, the influence of formulation on biocide drift was not investigated.

1.1.1 Weather conditions

The drift potential can be influenced by weather conditions, especially wind speed, temperature, relative humidity and atmospheric stability (Miller & Bellinder 2001; Nuyttens et al. 2006a; Franke et al. 2010; Arvidsson et al. 2011). However, field measurements with field sprayers and subsequent modelling have shown that conditions with a combination of air temperature and relative humidity at constant wind speed have a stronger influence of the drift potential than conditions with different wind speeds at constant air temperature and relative humidity. An increase in air temperature from 13.4 °C to 21.7 °C and decreasing in relative humidity from 90% to 40% increases the drift potential from 4% to 10% at 1 m from the treated area. An increase in wind speed from 1 m s^{-1} to 5 m s^{-1} increases the drift potential from 7% to only 9% (Nuyttens et al. 2006a). The reason for this is that the droplet diameter gradually decreases due to the evaporation of the water contained in the droplet (Holterman et al. 1997; Miller & Bellinder 2001; Miller 2003; Hilz & Vermeer 2013) and this is more influenced by air temperature and relative humidity than by wind speed.

Other studies assume that boom height and wind speed are the most important factors influencing total drift, followed by air temperature, driving speed and vapour pressure deficit (Arvidsson et al. 2011). The influence of wind speed is closely related to the type of nozzle. Droplet sizes less than 100 µm in diameter are traditionally considered drift-prone (Elliott & Wilson 1983; Nasr et al. 2002; Holterman 2003; Miller 2003; Hofman & Solseng 2004; Franke et al. 2010; Hilz & Vermeer 2013; Gil et al. 2014; Świechowski et al. 2014; Gregorio et al. 2016; Gaytan et al. 2018; Miranda-Fuentes et al. 2018). Droplets larger than 100 µm in diameter resist evaporation much more than smaller droplets due to their larger volume-to-surface area ratio, and droplets with a diameter of 50 µm or less evaporate completely before reaching the target (Hofman & Solseng 2004). Therefore, nozzle types with a larger proportion of droplets with a diameter of less than 100 µm and a high wind speed have a larger contribution to the total spray drift than air temperature and relative humidity (Arvidsson et al. 2011). In a light breeze and a constant wind speed of 1.3 m s^{-1} parallel to the ground, a 1 µm droplet released from a height of 3 m can theoretically travel over 150 km downwind before settling (Matthews et al. 2014). However, it is more likely that this droplet will evaporate first. Thus, when a pesticide spray loses all of its diluent through evaporation, it creates a very small particle of concentrated chemical that can then be carried by air currents over much greater distances (Matthews et al. 2014).

In summary, the influence of drift due to weather conditions makes no difference between using a conventional field sprayer and a knapsack sprayer. The influence of weather conditions on the movement of the spray jet and droplets is identical, and droplet size also plays an important role in both devices. The evaporation and movement of droplets smaller than 100 µm is significantly influenced by air temperature, relative humidity and other climatic conditions (Hofman & Solseng 2004).

1.1.2 Application factors

The next parameter that influences drift and has the same weight as weather conditions is the application factor. The term application factor includes the parameters sprayer type, nozzle type and size, spray pressure, application height and angle (Franke et al. 2010).

It is now useful to define some of the terms and expressions used in this final report. A spray is a dispersion of droplets that penetrate the surrounding medium at high velocity (Yule & Dunkley 1994). The nozzle or a device that produces a spray is called an atomiser. The general characteristics of a spray can be summarised by its shape, structure and droplet size (Hewitt et al. 2002). Nozzles have three main functions: They regulate the flow, they atomise the mixture into droplets and they distribute the spray in a desired structure (Hofman & Solseng 2004). Different applications for sprays have different requirements for these properties. Spray nozzles can be divided into narrow-angle (<30°), medium-angle (30°-70°) and wide-angle (>70°) types (Nasr et al. 2002). Most agricultural nozzles have an angle of 65° to 120°, and the three basic spray patterns are flat spray, hollow cone and full cone (Hofman & Solseng 2004). For biocidal applications, there is no information on the most commonly used nozzles available.

Back to the application factors that influence drift potential. As described above, drift risk is closely related to droplet size (Hilz & Vermeer 2013) and also to the composition of the droplet spectrum (Franke et al. 2010). The fact that droplets smaller than 100 µm are very susceptible to drift has already been discussed above. Now it is time to discuss the effects on droplet size generation. One factor is the nozzle type. Full-cone nozzles produce larger droplets than flat fan nozzles and hollow-cone nozzles produce smaller droplets than flat fan nozzles (Hofman & Solseng 2004). However, flat fan nozzles are not the ultimate solution; it is important to choose a nozzle that produces the desired spray pattern. The specific use of a nozzle, e.g. large-scale application of herbicides or spraying insecticides on row crops, determines the type of nozzle required. Therefore, multiple nozzle sets are needed for a variety of applications (Hofman & Solseng 2004; Grisso et al. 2019). Information sheets from nozzle manufacturers are helpful in selecting the right nozzle for the application of plant protection products (Teejet 2013).

Furthermore, the nozzle orifice and the spray pressure also have a major influence on droplet size (Hilz & Vermeer 2013). While small nozzle orifices produce small droplets, large nozzle orifices produce larger droplets (Hofman & Solseng 2004). Holterman et al. (1997) also observed a greater drift potential for nozzles with small orifices. The difference between nozzles with 2 mm orifice and 4 mm orifice was not as large as the difference between 4 mm orifice and 8 mm orifice at the same pressure (Holterman et al. 1997). Thus, the spray pressure has a greater influence on the droplet size than the orifice. To explain this, it is first important to know how a droplet is formed. The spray solution comes out of the nozzle in a thin layer and droplets form at the edge of the layer. At higher pressure, the layer becomes thinner and this layer breaks down into smaller droplets (Hofman & Solseng 2004). Therefore, a high spray pressure produces a larger number of small droplets (Miller & Bellinder 2001). However, pressure and droplet size depend on the specific application. Larger droplets are more effective for many herbicide applications, while finer droplets are more suitable for insecticide and fungicide applications (Pringnitz et al. 2001). If this is not taken into account and attempts are made to minimise drift with larger droplets, the biological efficacy of the product applied may be compromised (Nuyttens et al. 2007).

In addition, nozzles with larger spray angles produce smaller spray droplets than a nozzle with the same application rate but a narrower spray angle (Hofman & Solseng 2004). An angle reduction of 10° is sufficient to observe an effect. Miller (2003) compared different nozzle angles and a conventional 120° flat fan nozzle produced more drift than the 110° reference nozzle (Miller 2003). However, wide-angle nozzles have the advantage of being placed closer to the target than narrow-angle nozzles. However, the advantages of lower nozzle placement outweigh the disadvantage of slightly smaller droplets (Hofman & Solseng 2004). The drift potential can have a ratio of up to a factor of 10 between the lowest and highest values at a boom height of 1 m and 0.35 m above cut grass (Holterman et al. 1997). This does not mean that the correct boom height is as close as possible to the target and the stand. The correct boom height depends on spray coverage and biological efficacy, and these in turn depend on the nozzle angle (Hofman & Solseng 2004). Overlapping the spray swaths by about 30% results in uniform application and spray coverage (Miller 2003).

In summary, the term application factor encompasses many major factors that significantly influence spray drift. When using a conventional field sprayer or a knapsack sprayer, the choice of the right nozzle type and size, the application pressure used and the height are equally important and influence drift equally.

1.1.3 Operator care, attitude and skill

Care, adjustment and skill of the operator are very important when using a knapsack sprayer compared to a mechanised sprayer (Franke et al. 2010). Variations in drift, however, are more common when using a knapsack sprayer. A knapsack sprayer is a hand-held sprayer (Horne 2019) that is carried on the back (WHO 2018). When a knapsack sprayer with a single nozzle boom is used oscillating over a target area, as is often the case, the application result can be poor due to under- and overdosing, and drift can be relatively high due to varying tip heights (Miller & Bellinder 2001). In addition, the angle of spray can vary greatly between knapsack sprayer operators, which also affects drift (de Snoo & de Wit 1993). Studies show that operators work at full speed early in the morning but are tired at the end of the day. It is also difficult to work at the same walking speed (Bateman et al. 2007). Therefore, the first hectare may be over-applied while the last hectare is under-applied (Miller & Bellinder 2001; McAuliffe & Gray 2002). This led not only to under- and over-application, but also to drift due to the difference in working pressure (Miller & Bellinder 2001). However, training did not improve the ability of individuals to run at a given speed, but only reduced fluctuations around the mean (Spencer & Dent 1991).

Knapsack sprayers are the most important device for applying plant protection products in many parts of the world (Herbst & He 2008; Matthews 2016), but they are also the most frequently misused device due to a lack of mechanisation options.

1.2 Measures to reduce drift

As explained above, there are many factors that influence drift. However, there are also just as many measures that counteract drift. One of the most important factors is the interaction of weather conditions and droplet size. While technical solutions solve many problems, they are not a panacea, and weather is neither predictable nor controllable. Small, drift-prone particles cannot be completely eliminated, but drift can be reduced and kept within acceptable limits (Hofman & Solseng 2004) if the following factors are taken into account.

According to good agricultural practice, plant protection products should not be applied at wind speeds above 5 m s^{-1}, air temperatures above 25 °C or relative humidity below 30% in order to reduce drift (BMELV 2010). There is currently no guideline for the application of biocidal products, but there is no reason why it should be different in this area.

Selecting suitable nozzles and switching to low-drift nozzles are important factors in reducing drift. However, this is the responsibility of the user. One problem, however, is that conventional nozzles are supplied as standard when new sprayers are first fitted. Economic considerations can influence users decisions, as standard nozzles are cheaper than drift-reducing types (Nasr et al. 2002). To simplify the selection of the right low-drift nozzles for the application of plant protection products, nozzles are tested and approved by the JKI (Julius Kühn-Institute). On request, nozzles can also be classified in drift mitigation classes of 50%, 75%, 90% and 95% (JKI 2018). Approved flat spray nozzles are included in the "Descriptive List" and published in the Federal Gazette. A system like this would be suitable for nozzles used for biocides applications as well. However, the results of the already existing lists for the application of plant protection products cannot be directly transferred as the testing is conducted using specific agricultural equipment.

In general, air injection nozzles have the highest drift mitigation potential, followed by low-drift nozzles and standard flat fan nozzles (Nuyttens et al. 2006b). The biological effect of plant protection applied with low-drift nozzles is still under discussion. However, no clear influence of the nozzle type on the effectiveness of pest and disease control could be found yet (Knewitz et al. 2002; Doruchowski et al. 2017). Differences could only be observed in the use of herbicides. The performance of systemic herbicides increased more uniformly with decreasing droplet size than that of contact herbicides. In addition, decreasing droplet size improved herbicide performance on difficult-to-wet crops than on easy-to-wet crops (Knoche 1994). Thus, spray application of chemicals can be effective but inefficient, and it is a balancing act between biological effectiveness, economic considerations and conservation of non-target areas. This statement also applies to the use of biocidal products.

Other technologies that can be used to reduce drift include shielded sprayers, boom height control systems and constant flow systems. Shielded spray booms, protective cones with a sprayer or completely covered spray booms, can reduce drift by 50% or more (Porskamp et al. 1997; Hofman & Solseng 2004; van de Zande et al. 2007). Especially with knapsack sprayers, the use of a drift shield can significantly reduce drift. Awadhwal et al. (1991) observed a drift mitigation of 63%. This measure could be transferred to biocides applications using knapsack sprayers.

Boom height control systems are widely used on modern field sprayers. It is known that drift increases with the vertical movement of the boom. An active height control system on a passively suspended boom can reduce this problem. This can be realised with sensors that measure the height of the boom tips above the ground and adjust accordingly. A significant 54% reduction in drift was found when the boom height was reduced from 70 to 50 cm above bare soil. When the boom was lowered from 70 to 30 cm, drift was reduced by 80% (Jong et al. 2000). The economic incentive for the farmer is that the purchase of spraying systems with boom height control is financially supported (Agricultural Investment Promotion Program, (JKI 2020)). As automation is not as widespread in biocides applications, the transferability of this measure is limited at the moment.

As described above, drift can also be influenced by working pressure, as working pressure affects droplet size (Hofman & Solseng 2004; Hilz & Vermeer 2013). Pressure control is standard equipment in an agricultural field sprayer. Most knapsack sprayers are not equipped with a pressure regulator, as the purchase of a conventional pressure regulator is far too expensive (Miller & Bellinder 2001). An alternative is to use constant flow valves called pressure relief valves. These valves are attached to a lance or boom line, usually just before the nozzle. They only open when their rated pressure is reached. As soon as the valve opens, the overpressure is reduced to the current pressure. The inlet pressure can reach up to 6 or 7.0 bar, but the outlet pressure remains at the control pressure. If the pressure drops below the current pressure, the valve shuts off the flow to the nozzle (Miller & Bellinder 2001; McAuliffe & Gray 2002). This would also be applicable for biocidal applications with knapsack sprayers.

The design of the application area can also significantly reduce spray drift. A spray-free buffer zone of 3 m can reduce drift in an adjacent ditch by 95% (de Snoo & de Wit 1998). In addition, a crop-free zone with tall and dense vegetation is more effective in reducing drift than bare soil. For example, hedgerows along field margins intercept a large part of the drift due to their filtering effect (Carlsen et al. 2006). Depending on the tree species, leaf thickness and time period during the vegetation period, hedges can therefore lead to a reduction in drift of more than 73% (Lazzaro et al. 2008) and even more than 90% when they are fully leafy (Wenneker et al. 2008). The transferability of this measure seems questionable for biocidal applications.

1.3 Techniques for drift measurements

Whether plant protection products or biocidal products are used, these products are often applied with hydraulic nozzles that use pressure to create a wide droplet size distribution. Due to increasing concerns about drift, a wider range of low-drift nozzles, such as air injection nozzles, have been introduced to reduce the finest part of the spray. While some treatments are successful, coarser sprays are less effective on small and super-hydrophobic targets. This could be related to the increased proportion of large droplets that bounce off and splash. It is therefore not possible to choose the right nozzle fitting for all applications. Test reports based on nozzle parameters and characteristics are helpful. These include information on drift behaviour, drift potential index or droplet size. The "Universal Table" on the JKI website (https://wissen.julius-kuehn.de/mediaPublic/AT-Dokumente/03-Abdrift/Verzeichnis-Verlustmindernde-Geraete.xlsx) provides an overview of validated nozzles and devices and their drift mitigation behaviour at different pressures.

1.3.1 Measurement of direct drift during outdoor application

For this nozzle validation, drift behaviour is an important factor that is measured in field tests. Drift is the portion of the applied active ingredient that is carried beyond the treated area (Stephenson et al. 2006; Hilz & Vermeer 2013). The part of the active ingredient that evaporates and is washed out is not considered drift (Hilz & Vermeer 2013; JKI 2013b). According to JKI Guideline 7-1.5 for measurements of drift during the application of plant protection products (JKI 2013b), the test area must be divided into a treated area and a measuring area. The treatment area is the area where the application is to take place. This area must be at least 50 m long and 20 m wide. The measuring area is the area downwind of the treated area where the active substance is measured as drift.

The spray liquid used shall be water mixed with a tracer in sufficient and detectable concentration. Each treatment shall be repeated at least three times and weather data shall be recorded continuously. The data to be recorded are wind direction, wind speed, air temperature and relative humidity. The weather station for recording these parameters must be located in the centreline behind the measuring area at a height of 1 m above the vegetation, but at least 2 m above the ground. Valid treatments shall be carried out at an air temperature not exceeding 25 °C, an average wind speed between 1 m s^{-1} and 5 m s^{-1} and an average wind direction not exceeding 30° from the perpendicular to the direction of travel.

To measure drift as ground sediment, passive drift collectors such as Petri dishes are placed on the ground. The arrangement of the Petri dishes depends on the task of the experiment. It is possible to place the Petri dishes 1 m, 2 m, 3 m, 4 m, 5 m, 7.5 m, 10 m, 15 m, 20 m, 30 m, 40 m, 50 m, 75 m and 100 m from the treated area. However, at least five distances must be chosen. For each distance, ten Petri dishes are to be set up at a distance of 1 m. The starting point for determining the distance from the treated area is e.g. half a nozzle distance from the outermost nozzle in agriculture and half a row width from the centre of the outermost row in orchards, vineyards and hops in case of testing for plant protection products. The amount of product collected is measured fluorimetrically or atomic absorption spectrometrically, depending on the type of tracer.

A guideline for measuring drift when controlling flying and crawling insects on a house wall does not yet exist. However, there is an Emission Scenario Document (ESD) for household and commercial insecticides, acaricides and other arthropod control products from the Organisation for Economic Co-operation and Development (OECD). This document describes two possible sub-scenarios that were used for the design of the experiments: Wall application for flying insects and chemical barrier for crawling insects. The simulated house is 17.5 m long, 7.5 m wide and 2.5 m high. For the flying insect application, whole walls are treated up to a height of 2.5 m, and for the crawling insect application, treatment of the foundations up to a height of 50 cm together with treatment of a 50 cm wide strip of soil around the house is assumed to be sufficient to prevent infestation. To measure drift as ground sediment, the first measurement point is 50 cm from the treated area (OECD 2008).

1.3.2 Classification by drift mitigation potential

The classification of drift mitigation is documented in the JKI guideline 2-2.1 "Procedure for entering plant protection equipment in the "Drift mitigation" section of the directory of loss-reducing devices of the descriptive list" of the JKI (JKI 2013a). According to this guideline, manufacturers can request the JKI to test devices and nozzles with regard to their drift-reducing properties. This test is a control according to §52 of the Plant Protection Act in the version of 6 February 2012 and includes drift tests according to guideline 7-1.5. However, the wind speed must be at least 2 m s^{-1} and the ground sediment must be measured at intervals of 3 m, 5 m, 10 m, 15 m and 20 m. In addition, at least three drift tests and at least 30 measured values per section must be carried out. In contrast to the basic drift values, the median values of these data are used to assess the drift mitigation properties and the regression line is calculated using the least squares method. The drift mitigation classes are calculated from these adjusted median values. These classes correspond to 50%, 75%, 90% and 95% of the adjusted median. The tested device is classified in the class whose regression line is not exceeded by the regression line of the device under test in the entire measuring range.

1.3.3 Drift-Potential-Index by wind tunnel test

Another way to classify the drift characteristics of nozzles is to measure the drift potential index (DIX) by wind tunnel tests. These wind tunnel tests were introduced to evaluate the drift potential of nozzles used in arable farming. The DIX value refers to the percentage of drift mitigation compared to a defined reference nozzle (Southcombe et al. 1997; Herbst 2001). This reference nozzle is defined as a commercial flat fan nozzle, Hypro ISO F110-03 (Bai et al. 2013; Butler Ellis et al. 2017). In the JKI guideline 7-1.8 for measuring the drift potential of nozzles in the wind tunnel, the TeeJet TP11003-SS is used as the reference nozzle (JKI 2021). The reference nozzle and the test nozzle are exposed to an air flow in the climatic wind tunnel to determine the drift potential under defined conditions. The spray resulting from the detachment of the spray curtain can then be measured in a plane perpendicular to the downwind flow direction. The operating parameters wind speed, relative humidity and air temperature are freely adjustable (Helck & Herbst 1998). The wind tunnel method has proven to be a valuable alternative to field measurements (Nuyttens et al. 2010). Compared to field drift tests, where the drift control of the entire spray system can be evaluated, wind tunnel tests provide a repeatable and economical way to measure the relative drift control potential of different nozzle types, sizes, pressures, heights and velocities. In addition to droplet size distribution, this method can also be used to consider important nozzle operating parameters (Taylor et al. 2004; Donkersley & Nuyttens 2011). The International Standard ISO 22856:2008 sets out general principles for measuring drift potential in wind tunnels under controlled laboratory conditions. According to these principles, a spray time of at least 5 s should be used and drift is recorded using 1.98 mm diameter polyethylene sampling lines laid both vertically and horizontally across the tunnel (ISO 2008). These principles are reflected in JKI Guideline 7-1.8 on measuring the drift potential of nozzles in the wind tunnel (JKI 2021) and in JKI Guideline 2-2.1 for the Testing and Approval of Plant Protection Equipment in the section "Drift Mitigation" of the Descriptive List of Drift Reducing Agents (JKI 2013a) and the classification is based on the drift potential index of the reference nozzle. For classification, the following values must be undercut:

- 50% drift mitigation: DIX < 49
- 75% drift mitigation: DIX < 28
- 90% drift mitigation: DIX < 18

1.3.4 Measurement of droplet size by light scattering

An indirect assessment of the drift potential of nozzles comes from the classification of droplet size. The British Crop Protection Council (BCPC), the American Society of Agricultural and Biological Engineers (ASABE) and the International Standard (ISO) have developed systems for classifying agricultural nozzles according to droplet size. All classification systems use standardised reference nozzle sets that delineate thresholds between five size classes depending on median volume diameter: very fine, fine, medium, coarse and very coarse (Southcombe et al. 1997; Fritz et al. 2012; ISO 2018; ASABE 2020).

First the droplet size of the test nozzle must be measured. However, different systems and methods for measuring droplet size can influence the results. Without exception, each laboratory has developed its own sampling setup and protocols for both sampling distance from the nozzle and simultaneous airflow velocities (Fritz et al. 2012). However, all these methods are based on the same principle: light scattering. When water particles are illuminated, they scatter light by diffraction, reflection and refraction. Therefore, light scattering is the most common method for studying and monitoring droplet size (Nasr et al. 2002). In this method, the scattered light from many hundreds of droplets is collected simultaneously in a laser beam (Fritz et al. 2012). The phase Doppler anemometry (PDA) technique is the most important technique for measurement in the laboratory (Lading et al. 1994). Two identical laser beams are crossed to form a pattern of light and dark stripes. The dimensions of this fringe area define the measurement volume and can be controlled by the optical arrangement. Particle/Droplet Image Analysis (PDIA) techniques are simpler than light scattering techniques such as PDA (Kashdan et al. 2003), because it is an image-based system that uses an automatic processing algorithm to analyse digital images (Sehsah & Ganzelmeier 2010). Based on these droplet size data, the median volume diameter can be determined and nozzles can be classified according to the BCPC, ASABE or ISO system.

Nozzle classification is very helpful for the user of crop protection products to select the right nozzle for daily application. The package inserts of crop protection products inform the user about the nozzle classification to be used. Each nozzle manufacturer publishes data sheets for their nozzles. According to the recommended nozzle classification, the user selects the nozzle and pressure and calculates the spray rate based on the travel speed and flow rate. The JKI can also help in choosing the right nozzle, it uses the BCPC system for classifying nozzles and a table of approved nozzles can be found on the homepage (https://wissen.julius-kuehn.de/at-dokumente/pruefung-und-listung/themen/abdrift).

2 Materials and methods

2.1 Experimental investigations for the derivation of drift values

Biocidal products are classified into 22 product types. For five of these 22 product types direct environmental pollution through drift is especially relevant, as the first project has already shown (Langkamp-Wedde et al. 2020). These are product type 2 (Disinfectants and algicides not intended for direct application to humans or animals), 3 (Veterinary hygiene), 10 (Building protection products), 18 (Insecticides, acaricides and products to control other arthropods) and 19 (Repellents and attractants). The areas with the highest drift potential are the control of the oak processionary moth (OPM), the control of flying and crawling insects on house walls and the removal of green growth on paths. Biocidal products of these product types are sprayed with devices such as cannon sprayers, helicopters, unmanned aerial vehicles, motorised knapsack mistblower and knapsack sprayers. Table 1 provides a list of applications where direct environmental impacts from drift are of high relevance and shows the experimental areas where environmental impacts are measured. Some investigation were carried out in the previous project (FKZ 3716 67 404 0) and some investigation were carried out in the current project (FKZ 3719 67 404 0). As the results of both projects will be taken up in the discussion, the main results from the previous project are also shortly summarised here.

Table 1: List of areas and techniques which a direct environment exposure to drift may occur and will be measured in the previous and current project.

Application	Application technique	Application area	Project
Control of oak processionary moth	Cannon sprayer (pneumatic atomizer)	Solitary tree	previous project
		Avenue	previous project
		Forest edge	previous project
	Helicopter	Avenue	previous project
		Forest edge	current project
	UAV	Solitary tree	previous project
	Motorised knapsack mistblower	Solitary tree	current project
	Cannon sprayer (hydraulic atomizer)	Avenue	current project
Control of flying and crawling insects	Knapsack sprayer	Container (Simulation of house wall)	current project
Removal of green growth		Paved path	current project

Source: own compilation, JKI

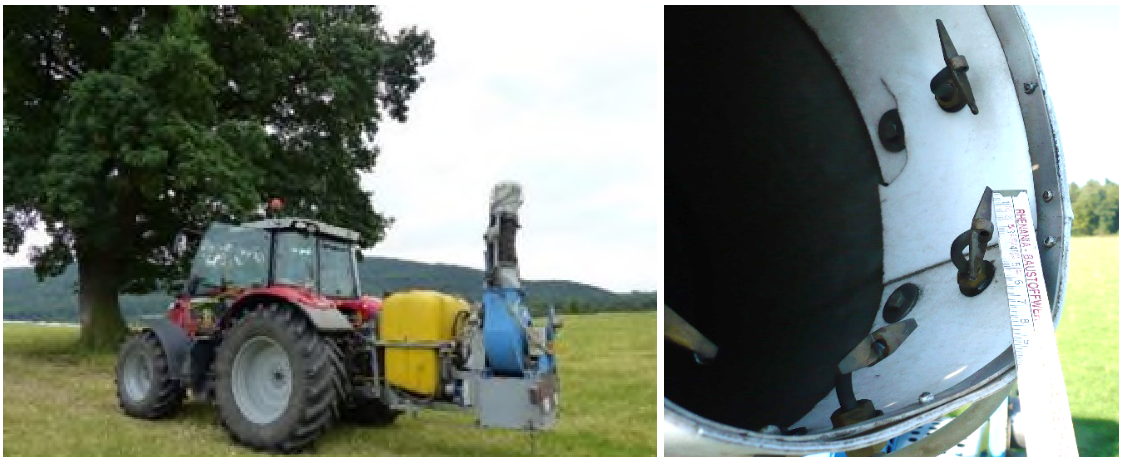
For all applications, water with the fluorescent dye Pyranine was used as the spray liquid. Pyranine is a green-yellow powdered sodium salt (trade name: Pyranine 120%, colour index: Solvent Green 7) and has a recovery rate of almost 100% (Herbst & Wygoda 2006). The recording of weather conditions during the trials was done with the weather station WENTO-IND (Lambrecht, Göttingen, Germany). This weather station measures air temperature, wind speed, wind direction and relative humidity with a frequency of 1 Hz. All applications were carried out at temperatures below 25 °C, wind speeds between 1 and 5 m s^{-1} and a wind direction of no more than 30° deviation from the mean wind direction according to the JKI guideline (JKI 2013b). For the assessment of drift mitigation, only trials where the wind speed was between 2 and 5 m s^{-1} were considered (JKI 2013a). To measure direct drift as ground sediment, Petri dishes were placed on wooden slats or earth spikes on the downwind side of the treated area. The Petri dishes had a diameter of 145 mm. The orientation of the Petri dishes depended on the treated area (see below). Petri dishes were also placed outside the measurement area to determine the blank value. Five minutes after each treatment, the Petri dishes were sealed, placed in a light-protected location and taken to the laboratory for tracer extraction and quantification. Tank samples were taken during the trials to check the application rate and to ensure that the tracer concentration was stable throughout the application.

2.1.1 Tested application technology for the application of biocidal products

2.1.1.1 Cannon sprayer with pneumatic atomiser

The cannon sprayer used was the tractor-mounted KWH B 612 cannon sprayer (KWH Holland BV, Rhenen, The Netherlands). The tank had a capacity of 600 L. The pump capacity of the sprayer was 150 L min^{-1} at a power take-off speed of 540 rpm. Eight pneumatic nozzles (size: 3 mm) in a 270 mm diameter spray tube were used (Figure 1). The working speed was approx. 1.5 km h^{-1}, the flow rate was 8.7 L min^{-1} for the eight nozzles and the working pressure was 1.5 bar. These device settings correspond to the settings in the practical use as made by the contractor. This cannon sprayer was used to measure the environmental exposure on the trial areas "solitary tree", "avenue" and "forest edge".

Figure 1: Tractor-mounted cannon sprayer KWH B 612 (left) with pneumatic atomiser (right).



Source: JKI

2.1.1.2 Cannon sprayer with hydraulic atomiser

The second cannon sprayer was the Dragone AZ2 (Dragone, Castagnole Lance, Italy). The tank had a capacity of 1000 L. The pump capacity of the sprayer was 88 L min^{-1} at a power take-off speed of 540 rpm. Eight nozzles were placed outside the air flow to spray the liquid into the air flow (Figure 2). AirMix 110-05 and ID-120-05 POM nozzles were used to determine their influence on drift behaviour. The working speed was 1.6 km h^{-1}, the working pressure was 8.0 bar, the flow rate was 3.22 L min^{-1} per nozzle, resulting in a total flow rate of 25.76 L min^{-1}. These device settings correspond to the settings in the practical use as made by the contractor. This cannon sprayer was used to measure the environmental exposure on the trial area "avenue".

Figure 2: Tractor-mounted cannon sprayer Dragone AZ2 (left) with hydraulic atomiser (right).

Source: JKI

2.1.1.3 Helicopter with a simplex spraying system

The helicopter used was the Eurocopter AS350 "Ecureuil" with an attached simplex spray system (Figure 3). The spray boom was used as a "long boom" with extensions and as a "short boom" without extensions. The "long boom" was 13.20 m long with 84 nozzles and the "short boom" was 10.80 m long with 68 nozzles. The dynamic working length was specified by the contractor as 30 m in both cases. When using the helicopter on the trial area "avenue", only the "short boom" with the right boom section of 5.40 m with 34 nozzles was used. The working pressure was 2.0 bar on the trial area "avenue" and 2.5 bar on the trial area "forest edge". The working speed was 60 km h^{-1} for all trials. Different nozzles were also used in these trials to determine their influence on the drift behaviour. The ID-120-05 POM and AirMix 110-05 nozzles have a flow rate of 1.61 L min^{-1} at 2.0 bar and 1.80 L min^{-1} at 2.5 bar.

Figure 3: Eurocopter AS350 "Ecureuil" (left) with attached simplex spraying system (right).

Source: JKI

2.1.1.4 Unmanned aerial vehicle (UAV) with a spaying system

The UAV used was the Agras MG-1 from DJI (Shenzhen, China). This UAV has eight rotor arms and the spaying system was mounted under four rotor arms. In the middle, under the technical units of the UAV, was the tank with a volume of 10 L (Figure 4). The nozzle used was AirMix 110-05 and the flow rate was 1.61 L min^{-1} at a pressure of 2.0 bar. These device settings correspond to the settings in the practical use as made by the contractor. The UAV was used to measure the environmental exposure at the trial area "solitary tree".

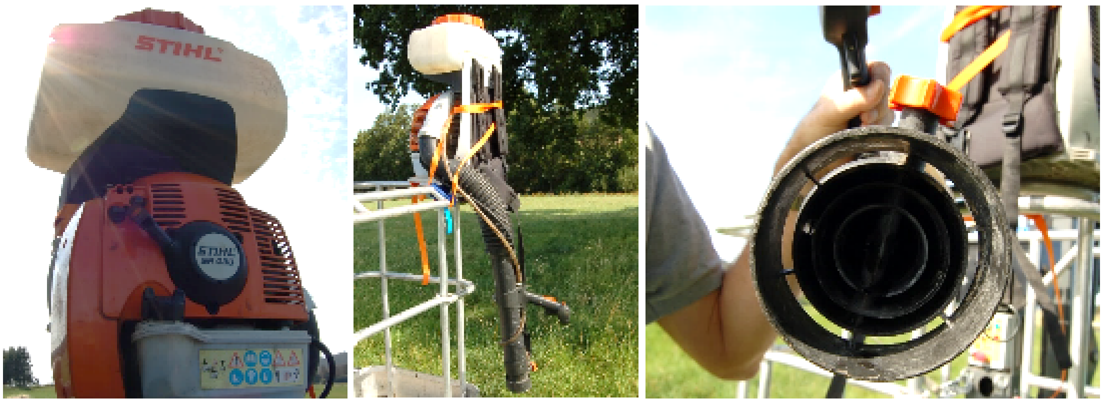
Figure 4: UAV Agras MG-1 from DJI (left) with attached spray system (right).

Source: JKI

2.1.1.5 Motorised knapsack mistblower with pneumatic atomiser

The motorised knapsack mistblower used was the SR 430 model from Stihl (Dieburg, Germany). This system used pneumatic atomisation (Figure 5). The spray liquid settles on the ribs in the spray tube and is atomised and applied by the air flow generated. The tank had a capacity of 14 L, although only 10 L were used for reasons of comparability with the other trials. The dosing device of this sprayer was set to level 3. This corresponds to a flow rate of 1.78 L min^{-1}. The maximum spraying range was 14.5 m. Therefore, a lifting platform was used to treat the tree crown. The motorised knapsack mistblower was used to measure the environmental exposure on the trial area "solitary tree".

Figure 5: Motorised knapsack mistblower (left, centre) with pneumatic atomizer (right).



Source: JKI

2.1.1.6 Knapsack sprayer with hydraulic atomiser

A REC 15 AC1 (Birchmeier Sprühtechnik AG, Stetten, Switzerland) was used as the knapsack sprayer. This knapsack sprayer is a pressure-controlled battery knapsack sprayer with CAS system. The pressure range is manually adjustable from 0.5 to 6.0 bar and the tank has a capacity of 15 L. In addition, the lance can be extended with an extension tube (Figure 6). Two different nozzles were used to determine the drift behaviour. A brass hollow cone nozzle included in the scope of delivery and the nozzle ID 90-015 C were used. Both nozzles were used with a working pressure of 2.0 bar. This knapsack sprayer was used to measure the environmental impact of direct drift on the trial area "container" and “paved path”.

Figure 6: Knapsack sprayer with a normal lance (left) and long lance (right).

Source: JKI

2.1.2 Trial areas to measure direct drift

2.1.2.1 Trial area “solitary tree”

The trial area "solitary tree" included a solitary oak as the treated area and the area next to the tree as the measuring area. The solitary tree was located in Langelsheim (51°57'22.9"N, 10°17'11.5"E), Lower Saxony, Germany. The solitary tree was 20 m high and the crown was 23 m long and 22.5 m wide, so that the total projection area was 517.5 m². The spray liquid was water with Pyranine (CAS number 6358-69-6) as a tracer dye at a concentration of 5 g L^{-1}.

Using a cannon sprayer with pneumatic atomisation, the application time was averaged 5:20 min and the application rate averaged 46 L per tree. This corresponds to a liquid rate of 890 L ha^{-1}. The track of the tractor was close to the tree trunk on the windward side, and the cannon sprayer sprayed the liquid directly into the crown.

When using a UAV, an application rate of 10 L per tree was used as a basis for the application time. This corresponds to a liquid rate of 193 L ha^{-1}. The UAV flew directly over the tree and sprayed the liquid into the crown. At that time, it was not yet possible to control the UAV via GPS and other automated air traffic controllers, so the UAV was controlled manually and flight path was guided directly over the tree regardless of the wind direction. Using a motorised knapsack mistblower, application time was also based on the application rate of 10 L per tree. The maximum spray range of this system was 14.5 m, so a lifting platform was used to treat the tree crown. The lift was on the windward side and the operator sprayed the liquid horizontally into the crown. Figure 7 shows the treatment of the trial area “solitary tree” with the three different application devices.

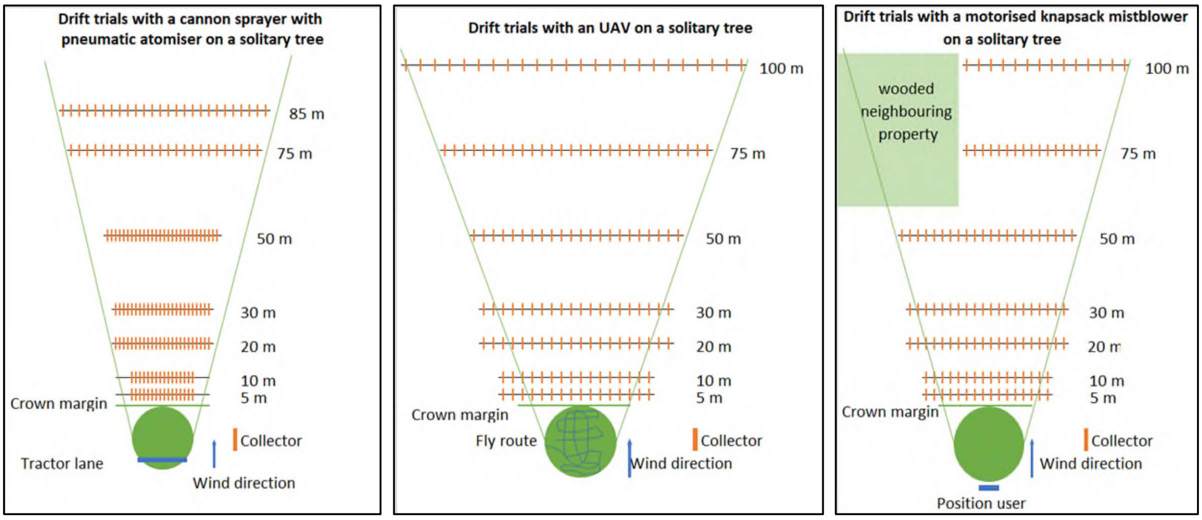
Figure 7: Use of a cannon sprayer with pneumatic atomisation (left), a UAV (centre) and a motorised knapsack mistblower (right) on the trial area "solitary tree".

Source: JKI

The measurement area was based on the mean wind direction of the day. Petri dishes were placed on earth spikes on the downwind side of the treated area as collectors. According to the JKI guideline for direct drift measurements, the treated area must be at least 50 m long and 20 m wide. However, in these trials, a kind of point application was carried out and the treated area was relatively small compared to the measuring area. Therefore, the guideline was optimised to capture as much of the total drift as possible. For this purpose, the collectors were distributed in a V-shape on the measuring area.

For the trials with the cannon sprayer, the distances from the crown edge were 5, 10, 20, 30, 50, 75 and 85 m. For the distances 5 m and 10 m 16 collectors were set up, for the distances 20 m, 30 m and 75 m 24 collectors, for the distance 50 m 28 collectors and for the distances 85 m 32 collectors. The distance between the collectors in the row was 2 m for the distances from 5 m to 50 m and 4 m for the distances of 75 m and 85 m. For the trials with a UAV, the measuring area was slightly optimised. The distance from the crown edge was 5, 10, 20, 30, 50, 75 and 100 m. For the 5 m and 10 m distance 16 collectors were set up, for the 20 m and 30 m distance 20 collectors, for the 50 m distance 22 collectors, for the 75 m distance 28 collectors and for the 100 m distance 24 collectors. The distance between the collectors in a row was 4 m for the 5 m to 75 m spacing and 6 m for the 100 m spacing. For the trials with a motorised knapsack mistblower, the measuring area had the same orientation as for the trials with a UAV. The distance to the crown edge was 5, 10, 20, 30, 50, 75 and 100 m. However, due to the wind direction on the measurement day, the measuring area for these trials was limited by a neighbouring forest area. Not all collectors could be set up at a distance of 75 m and 100 m. Therefore, only 17 collectors were set up for the 75 m distance and only 14 collectors for the 100 m distance. The distance between the collectors in a row was 4 m for a distance of 5 m to 75 m and 6 m for a distance of 100 m (Figure 8).

Figure 8: Schematic illustration of the trial area "solitary tree" during treatment with a cannon sprayer with pneumatic atomisation (left), an UAV (centre) and a motorised knapsack sprayer (right).



Source: own illustration, JKI.

2.1.2.2 Trial area “avenue”

The trial area "avenue" included an oak avenue as treated area and the area next to the avenue as measuring area. The avenue was a single row of oaks in Langelsheim (51°57'09.7 "N 10°16'14.2 "E) in Lower Saxony, Germany. The trees in the avenue were about 20 m high, the avenue was 125 m long and 23.5 m wide. The total projection area was 2937.5 m^2 (Figure 9). The spray liquid was water with Pyranine (CAS number 6358-69-6) as tracer dye at a concentration of 2 g L^{-1}.

For the trials with a cannon sprayer with pneumatic atomisation, the application time was on average 10:30 min and the application rate per tree on average 10 L. This corresponds to an average amount of liquid of 317 L ha^{-1}. The track of the tractor was on the windward side next to the trunk of the trees and sprayed the liquid from below into the crown. The cannon sprayer treated the avenue twice and was not equipped with a gap detection system.

For the trials with a cannon sprayer with hydraulic atomisation, the application time averaged 3:40 min. The working pressure was set to 8.0 bar and the avenue was treated once. This resulted in an average application rate of 403 L ha^{-1}. In addition, the trials were repeated four times with the AirMix 110-05 nozzle and four times with the ID-120-05 POM nozzle. Since the spray tube of the cannon sprayer with hydraulic atomisation could not be adjusted vertically by 90°, the contractor could not drive in the same track as the contractor with the cannon sprayer with pneumatic atomisation. The track of the tractor with the cannon sprayer with hydraulic atomisation was 15 m away from the avenue and sprayed the liquid from the windward side in the crown (Figure 9). The service providers explained that both methods correspond to the settings in practical use, as carried out by the contractor. This is also in line with the objective of these trials, the service providers should treat the trial areas with the current state of the art.

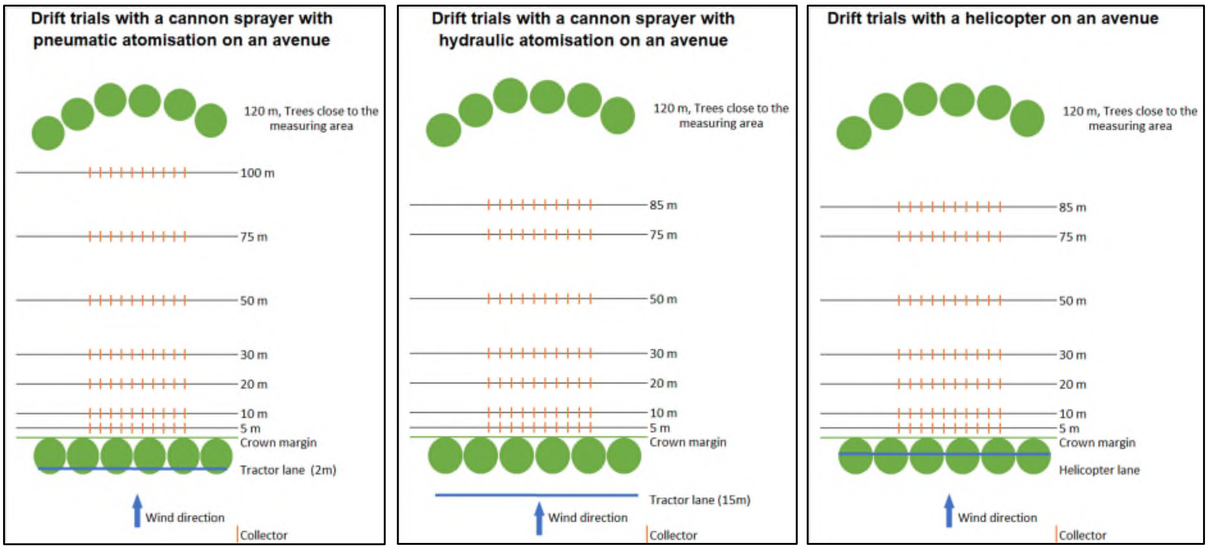
For the trials with a helicopter, the application time averaged 8 s and the application rate per tree averaged 1.5 L for the same area. As the avenue consisted of a single row of oaks, the helicopter flew over the centre of the row of oaks and sprayed the liquid only with the boom on the side facing the wind. The boom was 5 m long and had 34 nozzles. The helicopter application was repeated ten times with the Airmix 110-05 nozzles and five times with the ID-120-05 POM nozzles to see if different nozzles resulted in different drift values.

Figure 9: Use of a cannon sprayer with pneumatic atomisation (left), a cannon sprayer with hydraulic atomisation (centre) and a helicopter (right) on the trial area "avenue".

Source: JKI

The day for the measurements was selected according to the main wind direction. Thus, the measuring area was oriented at a 90° angle to the avenue, provided this corresponded to the mean wind direction. Petri dishes as collection containers were placed on wooden slats on the downwind side. According to the JKI guideline, it is sufficient to record a representative section of the entire drift. The distance between the collectors in the row was 2 m. Using a cannon sprayer with pneumatic atomisation, the distance from the crown edge was 5, 10, 20, 30, 50, 75, 100 m. For the trials with a helicopter and a cannon sprayer with hydraulic atomisation, the drift was measured up to 85 m instead of 100 m, as trees at the end of the measuring range influenced the results (Figure 10). The influence of these trees was determined after the analyses of the collectors, so that these collectors were not taken into account in the evaluation of the data.

Figure 10: Schematic illustration of the trial area "avenue" during application with a cannon sprayer with pneumatic atomisation (left) with hydraulic atomisation (centre) and with a helicopter (right).



Source: own illustration, JKI.

2.1.2.3 Trial area “forest edge”

The trial area "forest edge" included an oak forest edge as treated area and the area in front of the forest edge as measuring area. A cannon sprayer with pneumatic atomisation was used at a forest edge in Meine (52°21'31.8 "N, 10°36'15.1 "E) in Lower Saxony, Germany. The forest edge was treated over a length of 60 m. For the subsequent calculation of the ground sediment, a working width of 30 m was assumed, so that the total projected area was 1800 m^2. The application time was 5 minutes on average and the application rate per tree was 5 L on average. This corresponds to an average liquid rate of 241 L ha^{-1}. The tractor's track was on the downwind side and the cannon sprayer sprayed the liquid into the crown against the wind (Figure 11). The spray liquid was water with Pyranine (CAS Number 6358-69-6) as tracer dye with a concentration of 2 g L^{-1}.

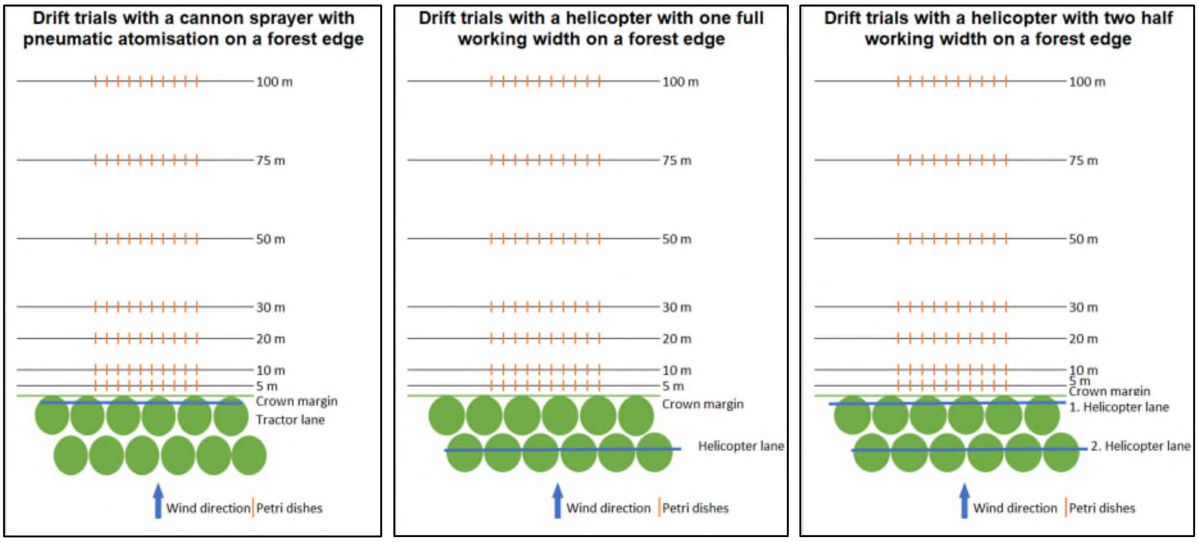
For the trials with a helicopter at the forest edge, a forest edge in Rennau, Lower Saxony (52°18'06.2 "N, 10°55'49.1 "E) was treated. The forest edge was treated over a length of 200 m and the dynamic working width was 30 m, so that the total projected area was 6000 m^2. Three application variants were tested to investigate the drift behaviour. In the first variant, the forest edge was treated with a "long boom" of 13.20 m and 84 nozzles. In the second variant, the forest edge was treated twice with half a "long boom" and in the third variant, the forest edge was treated with a "short boom" of 10.80 m and 68 nozzles. In the third variant, two nozzles were additionally examined for their drift behaviour. For this purpose, three repetitions with the AirMix 110-05 nozzle and three repetitions with the ID-120-05 POM nozzle were carried out in this variant. The application time was 14 s on average. The distance to the forest edge was half of a dynamic working width of 15 m. The spray liquid was water with Pyranine (CAS number 6358-69-6) as tracer dye at a concentration of 2 g L^{-1}.

Figure 11: Use of a cannon sprayer with pneumatic atomisation (left) and a helicopter (right) on the trial area "forest edge".

Source: JKI

The measuring area was aligned at a 90° angle to the edge of the forest, provided this corresponded to the mean wind direction, and was designed identically to the measuring area of the trial area "avenue". For the trials with a cannon sprayer with pneumatic atomisation and with a helicopter, the collectors were placed at distances of 5, 10, 20, 30, 50, 75 and 100 m from the edge of the crown. In each series of measurements, 10 collectors were placed on wooden slats at a distance of 2 m (Figure 12).

Figure 12: **Schematic illustration of the trial area "forest edge" during application with a cannon sprayer with pneumatic atomisation (left), a helicopter with one full working width (centre) and a helicopter with two half working widths (right).**



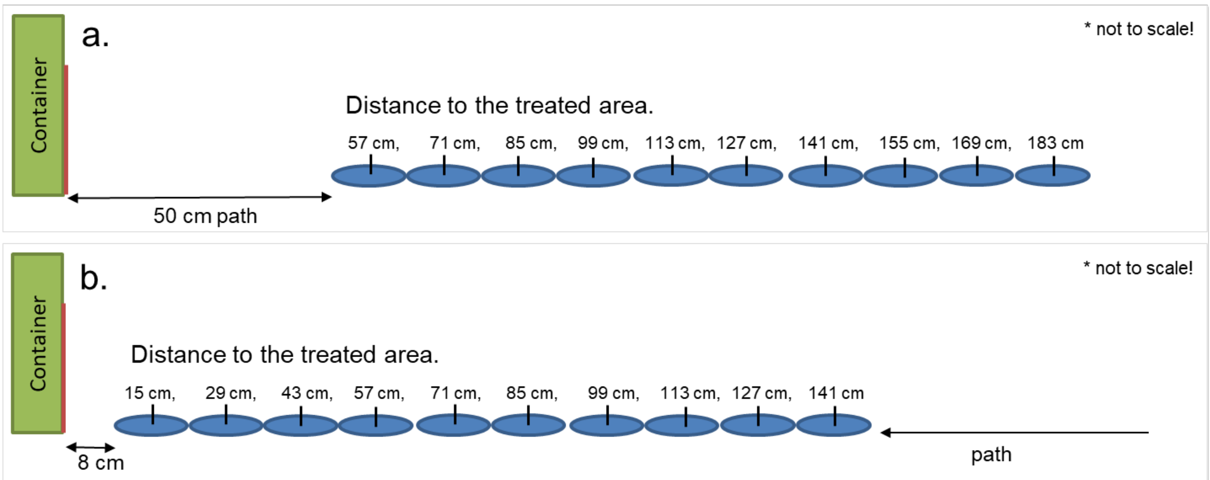
Source: own illustration, JKI.

2.1.2.4 Trial area "container"

The trial area "container" is an overseas container and simulates a house wall. The long side of the container was 7.55 m long and 2.45 m high and was covered with a ribbed plexiglass pane to simulate the structure of the house wall.

The container was used to study two scenarios for insect control by spraying based on the OECD ESD: wall application for flying insects and chemical barrier for crawling insects. For flying insect control, the entire wall was treated; for crawling insect control, a foundation was sprayed at a height of 50 cm. In order to be able to measure the direct drift up to 1.80 m in front of the container, trials have been carried out with two walking paths for the user (Figure 13). For path "a" the user stands directly in front of the container and uses the "normal" lance and for path "b" the user stands behind the measuring area and uses the "long" lance. When treating the entire wall, the user used the "long" lance and it was thus not possible to use path "a". Therefore, only path "b" was used when treating the entire wall (Figure 14). During all trials, the user walks backwards and treats the container with up and down movements of the lance. Petri dishes used as collectors had a diameter of 145 mm and were placed close together. 10 collectors per row were used and placed in 8 rows. For the evaluation of the data, the collectors of both pathways were subsequently combined.

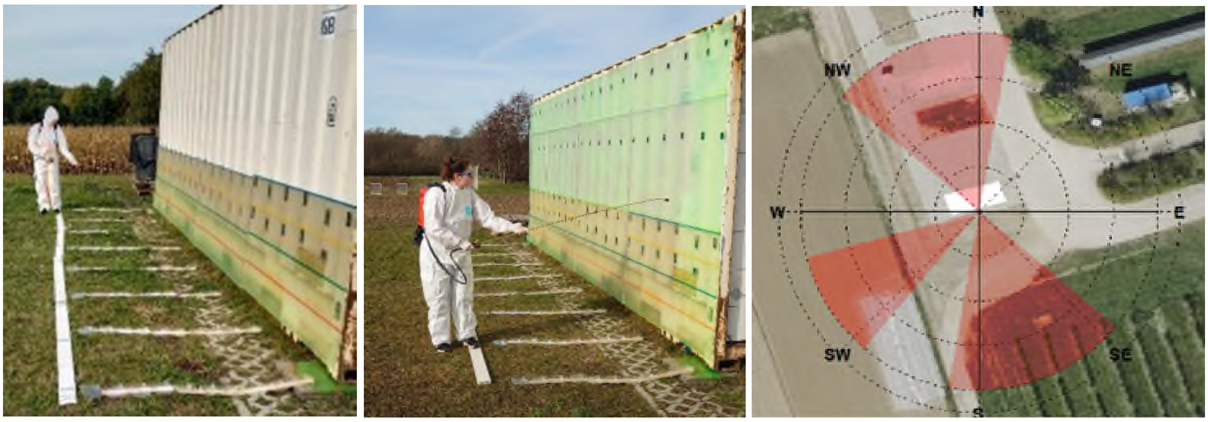
Figure 13: Schematic illustration of the trial area "container" during application with a knapsack sprayer with pneumatic atomisation for path "a" and "b".



Source: own illustration, JKI.

To measure the influence of the wind direction, the trials were carried out in three wind directions: parallel wind direction (WSW), orthogonal wind direction (SSE) and wind shadow of the container (NNW). In addition, the influence of the included brass hollow-cone nozzle and an IDK 90-015 C nozzle on the drift behaviour was tested. The spray liquid used was water with Pyranine (CAS number 6358-69-6) as the tracer dye at a concentration of 5 g L^{-1}.

Figure 14: User treated a chemical barrier with a knapsack sprayer (left), the entire wall (center) and corridors of the three wind directions (right).

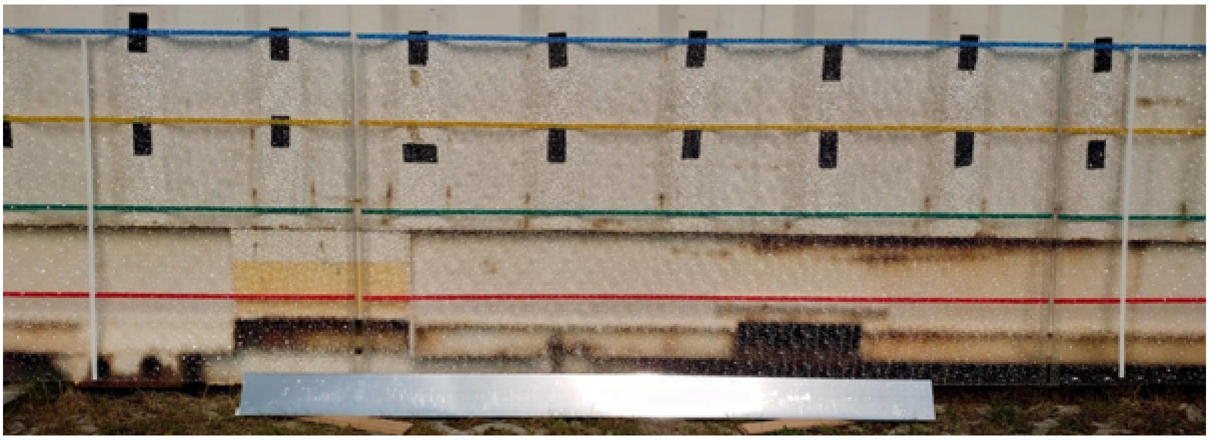


Source: JKI

In addition, a third fraction was measured, the runoff. The runoff is the fraction of the applied product that reaches the ground during a treatment. To measure runoff, an area 75 cm high and 300 cm wide was treated. The liquid was collected with a 2 m long metal profile (Figure 15), prepared with a thin fleece. The measuring area was larger than the collection area to reduce the influence of the user. While treating the area, the user walked backwards and moved the lance up and down. To prevent the user from spraying directly into the profile, a V-shaped metal profile was used. This profile was positioned under the plexiglass pane so that the liquid could run off and fall onto the thin fleece, but the second side of the profile protected the fleece from direct splash water. A second measure to protect the fleece from direct splash water was to stop the application 25 cm above the profile. Thus, only the area between the red, blue and white lines on Figure 15 was treated.

After application and a short waiting time of one minute, the profile was removed and the fleece was placed in wide-mouth tubes for laboratory analysis. Two application rates were tested to investigate the runoff behaviour. The first application rate was 100 mL m^{-2} according to the label of an algaecide, hereafter referred to as “full application rate”, and the second application rate was 50 mL m^{-2}, hereafter referred to as “half application rate”. After each application, the knapsack sprayer was weighed to determine the actual application rate. The spray liquid used was water with Pyranine (CAS number 6358-69-6) as the tracer dye at a concentration of 2 g L^{-1}.

Figure 15: Treated area and metall profile for measuring runoff.



Source: JKI

2.1.2.5 Trial area “paved path”

A paved path was used as the trial area to measure drift during algae removal from paths. The user used a knapsack sprayer with a short lance and walked backwards. The treated area was 1 m wide and 8 m long. There were 10 collectors close together on the measuring area. Each row had a distance of 50 cm to the next row. The spray liquid used was water with Pyranine (CAS number 6358-69-6) as the tracer dye at a concentration of 5 g L^{-1}.

Figure 16: User treated a paved path with a knapsack sprayer.

Source: JKI

2.2 Laboratory experiments for the classification of nozzles

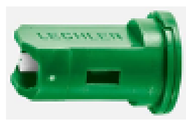
The experimental investigations to derive drift values in the laboratory were carried out with different nozzles to compare their behaviour with regard to their drift potential.

A new knapsack sprayer was invested for the trials on a container wall. The scope of delivery included a hollow cone nozzle made of brass with a nozzle size of 1.7 mm. Based on the flow rate of the brass nozzle, a comparison nozzle was determined. At 2.0 bar, the flow rate of the brass nozzle was 0.4 L min^{-1}. Accordingly, the nozzle IDK 90-015 C with a flow rate of 0.46 L min^{-1} was selected using the knapsack sprayer at 2.0 bar (Table 2). The nozzle IDK 90-015 C is an injector flat spray nozzle with a nozzle orifice of 015. This nozzle is approved for orchards and vineyards with a pressure range between 2.0 and 20.0 bar. The droplet size distribution is very coarse to medium (JKI 2018).

For the trials with cannon sprayer and helicopter with hydraulic atomisation, the two injector flat jet nozzles AirMix 110-05 and ID-120-05 POM were used. These nozzles have an identical nozzle orifice of 05, a flow rate of 1.61 L min^{-1} and a similar spray angle of 110° and 120° (Source: own compilation, JKI.

Table 3). The AirMix 110-05 is approved for arable farming in associations at a pressure between 1.0 and 6.0 bar. The droplet size distribution is very coarse to coarse. The ID-120-05 POM is also approved for arable farming in associations, but the approved pressure range is 2.0 to 8.0 bar. The droplet size distribution of this nozzle is very coarse (JKI 2018).

Table 2: Nozzles for examinations with a knapsack sprayer.

Name	Brass nozzle	IDK 90-015 C
		
Nozzle type	Hollow cone nozzle	injector flat jet nozzle
Manufacturers	Birchmeier	Lechler
Nozzle orifice/size	1.7 mm	015
Spraying angle	-	90°
Flow rate at 2.0 bar using knapsack sprayer [L min^{-1}]	0.4	0.46
Approved pressure range [bar]		2.0 - 20.0

Source: own compilation, JKI.

Table 3: Nozzles for examinations with a cannon sprayer and a helicopter.

Name	AirMix 110-05	ID-120-05 POM
		
Nozzle type	injector flat jet nozzle	injector flat jet nozzle

Name	AirMix 110-05	ID-120-05 POM
Manufacturers	Agrotop	Lechler
Nozzle orifice/size	05	05
Spraying angle	110°	120°
Flow rate at 2.0 bar, list data [L min^{-1}]	1.61	1.61
Approved pressure range [bar]	1.0 - 6.0	2.0 -8.0

Source: own compilation, JKI.

2.2.1 Measuring of the distribution accuracy of nozzles

In order to measure the distribution accuracy of nozzles, the single nozzle test bench was used as a test facility (Figure 17). Working height and working pressure can be adjusted individually. Water is used as spray liquid, which is collected in 2.5 cm wide troughs and collected in plastic cylinders. The water level in the cylinders is measured with a laser scanner and the flow rate is determined in mL min^{-1}. With this test equipment it is possible to determine the distribution accuracy of nozzles across their entire jet width and to identify differences. This characteristic is called spray pattern. And this spray pattern can be narrow or wide, with a plateau or with a tip, depending on the nozzle type.

Figure 17: Single nozzle test bench for measuring the distribution accuracy of nozzles (left) and spray pattern in the plastic cylinders (right).

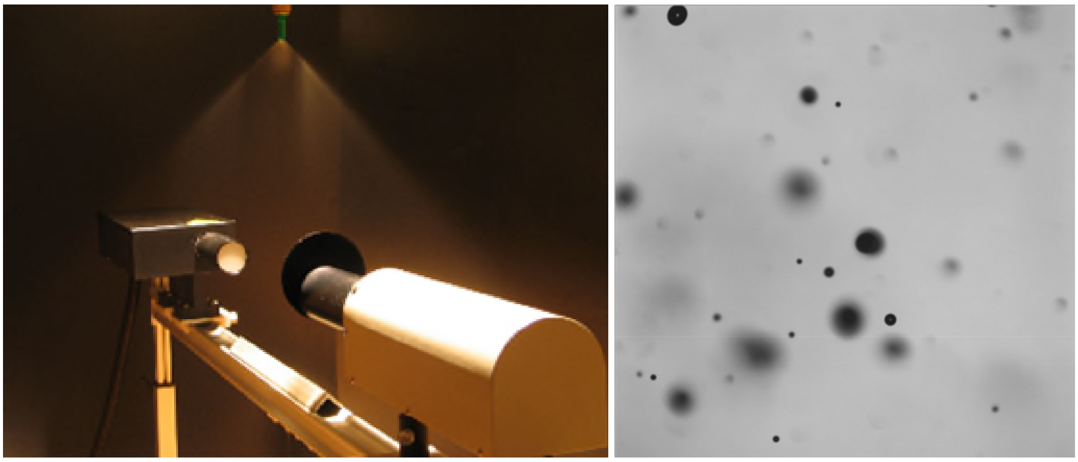
Source: JKI

To measure the distribution accuracy of the nozzles for the knapsack sprayer (brass nozzle and IDK 90-015 C), the working height was set to 20 cm. A distance of 20 cm is the maximum distance between the nozzle and the wall when treating the container. To measure the influence of the working pressure on the spray pattern, the working pressure was set to 2.0, 3.0, 5.0 and 7.0 bar. To measure the distribution accuracy of the nozzles used with cannon sprayer and helicopter (AirMix 110-05, ID-120-05 POM), the working height was set to 50 cm (reference value) and the nozzles were tested in a formation of 5 nozzles. The distance to each other was 25 cm. To measure the influence of the working pressure on the spray pattern, the working pressure was also set to 2.0, 3.0, 5.0 and 7.0 bar. Each pressure range was repeated three times with each of these four nozzles.

2.2.2 Measuring of droplet size distribution of nozzles

To measure the droplet size distribution of nozzles, the system "VisiSizer" from Oxford Lasers (Oxfordshire, UK) was used. This system uses an automated PDIA method to obtain information about the mean diameter from a series of images of a spray. The system consists of a pulsed light source, a camera and a computer. The PDIA technique uses a backlit image field in which the laser output is extended by a diffuser to break the coherence of the laser light. A CCD digital camera captures images at 30 Hz, with an image resolution of 1008 x 1008 pixels and a data rate of up to 7500 droplets per second. Droplets that touch the edge of the image are automatically sorted out, as are droplets that occupy less than 10 pixels. The pulsed laser freezes the movement of the droplet and provides illumination for the images. A grey level threshold is set and the automatic algorithm then scans across the image pixel by pixel and determines which pixels correspond to the background and which to the droplet based on the set threshold. In order for the droplets to be measured accurately, the intensity gradient at the edge of the droplet is measured to determine the degree of focus (Figure 18).

Figure 18: Drop size analysis with the VisiSizer system from Oxford Lasers (left) and an image from the digital camera for evaluating the drops (right).



Source: JKI

To measure the droplet size distribution, the four nozzles used were mounted alternately on a carrier at a distance of 50 cm from the laser. The working pressure was set to 2.0, 3.0, 5.0 and 7.0 bar. During the measurements, the carrier moves in 10 cm long paths over a rectangular area in order to capture the entire spray. The measurement was considered complete when 10,000 droplets had been documented. The spray water had a temperature of approx. 20 °C. The ambient conditions were kept constant with an air temperature of 20 °C and a relative humidity between 70 and 80%. The measurement of each nozzle was repeated three times at each pressure setting.

2.2.3 Measuring of the drift potential index of nozzles

Measuring the drift potential index (DIX) using wind tunnel tests is one way to classify the drift potential of nozzles used in arable farming. In this study, the wind tunnel was used to determine the drift potential of the AirMix 110-05 and ID-120-05 POM nozzles. The drift potential of the brass nozzle and the IDK 90-015 C was not determined because the application areas of these two nozzles do not correspond to the requirements of the nozzles that are actually measured with the wind tunnel.

The wind tunnel was 2.5 m wide and 1.6 m high (Figure 19). During the measurements, the wind speed was 2 m s^{-1}, the relative humidity was 80% (± 5%) and the air temperature was 20 °C. To test the influence of the working pressure on the drift potential, the pressure was set to 2.0, 3.0, 5.0 and 7.0 bar. A frame with sampling lines made of polyethylene was set up at a distance of 50 cm. The sampling lines were 1 m long, had a diameter of 1.98 mm and were stretched at a distance of 10 cm. The spray liquid was water with Pyranine (CAS number 6358-69-6) as tracer dye at a concentration of 5 g L^{-1}. The spray duration was 5 s. After each measurement, the sampling lines were flushed with distilled water and the content of Pyranine in the flushing water was determined with a fluorometer. In relation to the fluorometer values of the sampling lines when using a reference nozzle, the DIX values were calculated and the drift mitigation classified. For classification, the following values must be achieved: 50% drift mitigation: DIX < 49, 75% drift mitigation: DIX < 28 and 90% drift mitigation: DIX < 18. The measurement was repeated three times for each nozzle type and pressure range.

Figure 19: Measurements in the wind tunnel to determine the drift potential in front view (left) and side view (right).

Source: JKI

2.3 Laboratory analysis

The collectors used in the experimental investigations to derive the drift values were stored in a dark, cool room and analysed as quickly as possible. For the analysis, the tracer (Pyranine) was extracted from the collectors with deionised water. For this purpose, 40 mL of deionised water was filled into the collectors and then shaken for 10 min on a turntable shaker at 65 rpm. The frequency and amplitude were chosen so that the inner wall of the collectors was completely washed around. For the analysis of the "runoff" fraction, 1000 mL of deionised water was filled into the wide-mouth glasses, the carrier materials - the contaminated fleece material pieces - were inserted in the glasses and shaken from two sides for 10 min on a turntable at 65 rpm. Frequency and amplitude were chosen so that the tracer detaches from the fleece. Preliminary tests showed a recovery rate of 95%, which was also taken into account in the calculation.

The analysis of the wash water from the different collectors was carried out with a fluorometer. Due to an improvement in laboratory equipment during the study, two different fluorometers were used, but this did not affect the results. One of the fluorometers used was the SFM 25 (Kontron Instruments, France). The excitation wavelength used was 401 nm and the emission wavelength used was 503 nm, respectively. The other fluorometer used was the RF-6000

(Shimadzu Duisburg, Germany). In this device, the excitation wavelength used was 405 nm and the emission wavelength used was 515 nm.

The laboratory work was not only optimised in 2020 by new measuring instruments, but the method of analysis was also revolutionised. The data were recalculated and no differences could be found. With the new analysis method, several calibration curves were created with the help of a defined stock solution by using the multi-point calibration technique. In this case, four calibration curves of 1, 10, 100, 200 and 1000 µg L^{-1} were required for the analysis of the container collectors in order to cover the entire measuring range. These calibration curves were also used to define the detection limit (LOD) and the quantification limit (LOQ).

2.4 Calculation of spray drift

To calculate the amount of sprayed deposit the application rate and the tracer rate have to be calculated at first using the equations 1 and 2:

$$AR = \frac{Q_{nozzles} * 600}{v * WW} \qquad (1)$$

$$TR = \frac{AR * c_{spray}}{100} \qquad (2)$$

where AR is the application rate [L ha^{-1}], $Q_{nozzles}$ is the sum of the liquid flow of all nozzles [L min^{-1}], v is the driving speed [km h^{-1}], WW is the working width [m], TR is the tracer rate [µg cm^{-2}], and c_{spray} is the real spray concentration of the tank sample [g L^{-1}].

The amount of spray drift deposit per area (β_{dep}) using the one-point-calibration and equation 3 (ISO 2005) or using the calibration curve and equation 4:

$$\beta_{dep} = \frac{\rho_{smpl} - \rho_{blk}}{\rho_{calib} - \rho_{blk}} * \frac{V_{dist} * c_{calib}}{A_{colle}} \qquad (3)$$

or

$$\beta_{dep} = \frac{(\rho_{smpl} - INT)}{\Delta_{calib}} * \frac{V_{dist}}{A_{colle}} \qquad (4)$$

where β_{dep} is the spray drift deposit [µg cm^{-2}]; ρ_{smpl} is the fluorometer reading of the sample [-]; ρ_{calib} is the fluorometer reading of the diluted stock solution [-]; ρ_{blk} is the fluorometer reading of the blank collector [-]; V_{dist} is the volume of the wash fluid [mL]; c_{calib} is the concentration of the diluted stock solution used [mg L^{-1}]; A_{colle} is the area of the collector for catching the spray drift [cm^2], INT is the intercept of the calibration curve [-] and Δ_{calib} is the slope of the calibration curve [mL $µg^{-1}$].

The amount of its percentage compared to the tracer rate was calculated using equation 5:

$$\beta_{dep\%} = \frac{\beta_{dep}}{TR} * 100 \qquad (5)$$

where $\beta_{dep\%}$ is the spray drift [%].

2.5 Statistical analysis

For the statistical analysis using Rstudio (R Core Team 2021) and the packages readxl (Wickham & Bryan 2019), lattice (Sarkar 2008), latticeExtra (Sarkar & Andrews 2019), agricolae (de Mendiburu 2021), tidyr (Wickham & Girlich 2022), ggplot2 (Wickham 2016), ggimage (Yu 2022), magick (Ooms 2021), gridExtra (Auguie 2017) and car (Fox & Weisberg 2019).

The measured drift values are displayed in a boxplot. The boxplot shows the median (50^{th} percentile), the 25^{th} percentile, the 75^{th} percentile and the extreme values of all measured values within one distance and one device. The median test was used to determine differences between devices at the same distance from the treated area (α = 0.05). In addition, different letters were used to indicate significant differences between the devices at the same distance from the treated area.

In accordance with the recommendation of the FOCUS Surface Water Working Group, the 90th percentile was used for the calculation of the basic drift values. The 90th percentile has been shown to best represent the worst-case scenario (Rautmann et al. 2001; FOCUS 2012). An exponential least squares regression line (best fit) was used to determine the basic drift values and the regression function was used to calculate the basic drift values for each distance. In this way, the basic drift values were calculated for the trial areas "avenue", "forest edge", "container" and "paved path". For the experimental plot "solitary tree", the maximum drift values were used instead of the 90th percentile. This application area is not described in the JKI guideline 7-1.5 (JKI 2013b) and was therefore optimised. To determine the maximum drift scenario, the measuring area was larger than the treated area. This resulted in very low drift values being measured even in the close range of the treated area, so that the 90th percentile was falsely lower than the true value. In order to better represent a worst-case scenario, the maximum value was chosen for this application area.

Similarly, the FOCUS Surface Water Working Group has recommended that a 90th percentile cumulative drift probability be used for all drift applications carried out during a single application season (multiple application). The basic concept of this approach is to select appropriate drift values such that the cumulative drift for the entire application season is equal to the 90th percentile of drift probabilities. It is assumed that the drift amounts for a single application are normally distributed with a mean μ and a standard deviation σ. Thus, for a series of n applications, the mean of all experimental observations is μ and the standard deviation is σ/n. For a single application, the cumulative 90th percentile drift amount in a normal distribution has a value of μ + 1.282 σ, this means that 90% of the values in the distribution are below the value that is 1.282 standard deviations above the mean. For a series of six applications, the cumulative 90th percentile of the drift quantity has a value of μ + 1.282 σ / 6 or μ + 0.523 σ. The cumulative percentile, which in a normal distribution corresponds to a value 0.523 standard deviations above the mean, is the 70th percentile. Therefore, a series of six individual spray drift events, each with a probability of 70th percentile, has an overall probability of 90th percentile for the entire application season. For rapidly degradable active substances, this rule ensures that multiple applications do not result in a lower risk in the assessment than a single application. In this study, the drift values for a twice and triple application for the trial areas "avenue" and "forest edge" were included. The single event percentiles for different numbers of applications per season are tabulated in Table 4.

Table 4: Percentile of individual spray drift events for n applications which are equivalent to cumulative 90th percentile spray drift for the season.

Number of applications	Drift percentile of a single Event
1	90
2	82
3	77
4	74
5	72
6	70

Number of applications	Drift percentile of a single Event
7	69
8	67
> 8	67 (assumed)

Source: FOCUS (2012)

At very low concentrations, there is a risk of misinterpretation. Therefore, the detection and quantification limits were used in these studies. These limits are important performance limits in method validation and describe the smallest concentration of an analyte that can be reliably measured with an analytical method. For this purpose, the calibration curves according to DIN 32465 (DIN 2008) were used with a probability of 95%. If the drift values were below these limits, the values were set to zero.

To identify drift mitigation measures, the drift mitigation potential was calculated according to the JKI guideline 2-2.1 (JKI 2013a). For this purpose, the median values of the measured drift values were calculated, a regression line was calculated according to the least squares method and the adjusted median values were recalculated. From these adjusted median values, the drift mitigation classes 50%, 75%, 90% and 95% were calculated and compared with the medians of the test device. The test device is classified in the class whose regression line is not exceeded in the entire measured distance range from the regression line.

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3 Results

3.1 Drift values for the trial area "solitary tree"

The trials with the pneumatic cannon sprayer and the UAV were carried out in the previous project (FKZ 3716 67 404 0). The trials with the motorised knapsack mistblower were carried out in the current project (FKZ 3719 67 404 0). As the results of both projects will be taken up in the discussion, the main results from the previous project are also shortly summarised here.

Meteorological conditions during the application

In the valid trials on the trial area "solitary tree", the average wind speed was between 2.34 m s^{-1} and 3.33 m s^{-1} and the average air temperature was between 19.1 °C and 20.7 °C. When using the pneumatic cannon sprayer and UAV, the average relative humidity ranged from 65.0% to 71.8%. When using a motorised knapsack mistblower, the relative humidity was significantly lower at 43.6%. The average meteorological conditions during the application are shown in Table 5. Some measurements were excluded because the deviation from the ideal wind direction was more than 30° or was outside the guidance values for mean wind speed of 1 m s^{-1} to 5 m s^{-1}. The number of valid measurements to generate drift mitigation measures is given in brackets, the wind speed must be at least 2 m s^{-1}.

Table 5: Mean values of meteorological conditions during the application on the trial area "solitary tree".

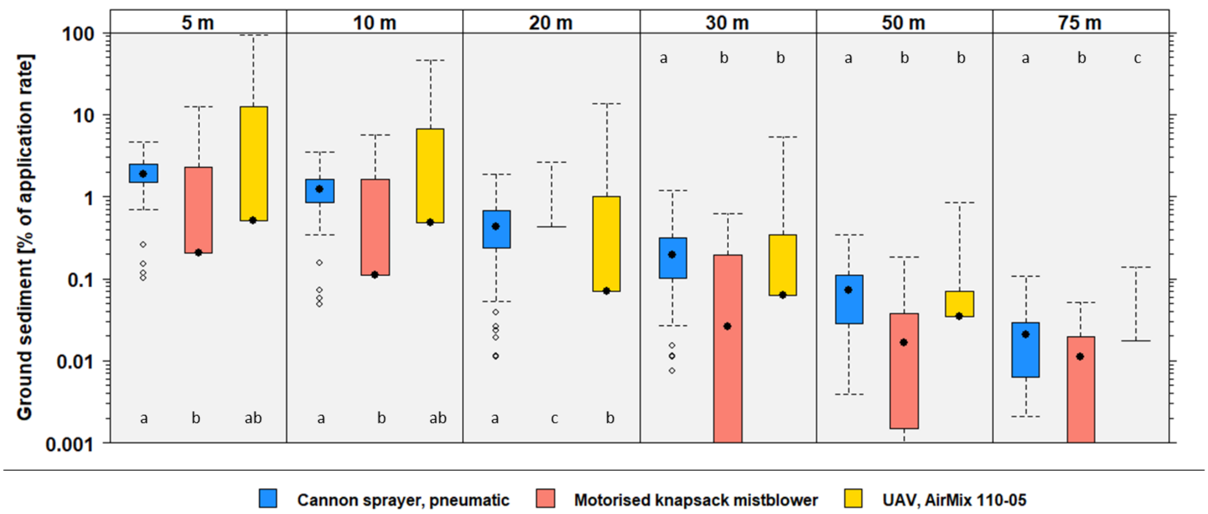
Parameters	Cannon sprayer - pneumatic		UAV AirMix 110-05		Motorised knapsack mistblower	
Temperature [°C]	20.2	± 0.80	19.1	± 0.63	20.7	± 0.37
Relative humidity [%]	65.0	± 1.47	71.8	± 2.81	43.6	± 2.25
Wind speed [m s^{-1}]	2.34	± 0.62	2.60	± 0.63	3.33	± 0.90
Wind direction [°] in relation to the ideal direction	10.1	± 13.5	-14.7	± 10.1	4.44	± 22.9
Valid measurements	8 (6)		6 (5)		6	

Source: own compilation, JKI

Measured drift values and recommended basic drift values

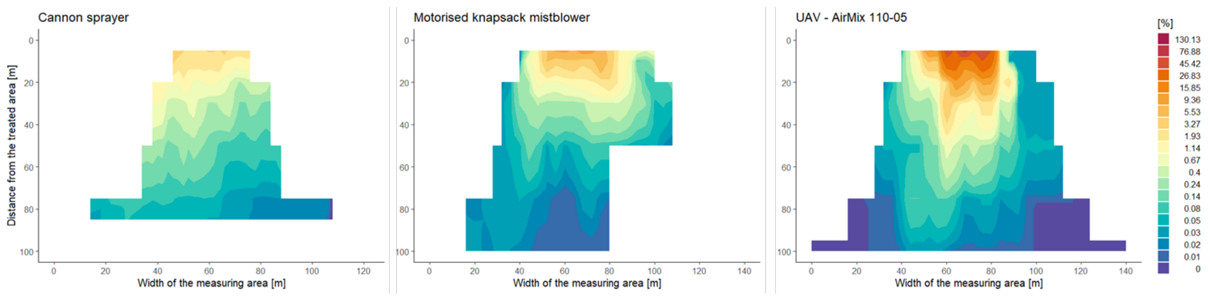
When using a pneumatic cannon sprayer, a motorised knapsack mistblower or a UAV, the drift decreased with increasing distance when applied a solitary tree (Figure 20). However, the variance of the drift was very different, especially at the same distance. When using a motorised knapsack mistblower and a UAV, the scatter of values was so large that the median of the values is not in the middle of the box but at the end of the box. Especially when using the UAV, the variance of the measured drift was sometimes extremely high. For a better understanding, Figure 21 shows the distribution of drift on the measuring area based on the median of the drift values. As described in chapter 2.1.2.1, the measuring area of the trial area "solitary tree" was adapted for the applications with motorised knapsack mistblower and UAV so that the entire drift can be recorded. At the same time, this adjustment also led to the variance of the data being very scattered. The variance of the drift values for the application with the cannon sprayer, on the other hand, does not scatter as much; here the measuring area was smaller and the entire drift was not captured. Due to the high scattering of the data, which is also due to the experimental design, the 90th percentile does not represent the worst-case scenario. Therefore, the basic drift values were derived based on maximum values.

Figure 20: Measured drift values in percent of the application rate on the trial area "solitary tree" (Median.Test, α = 0.05).



Source: own illustration, JKI

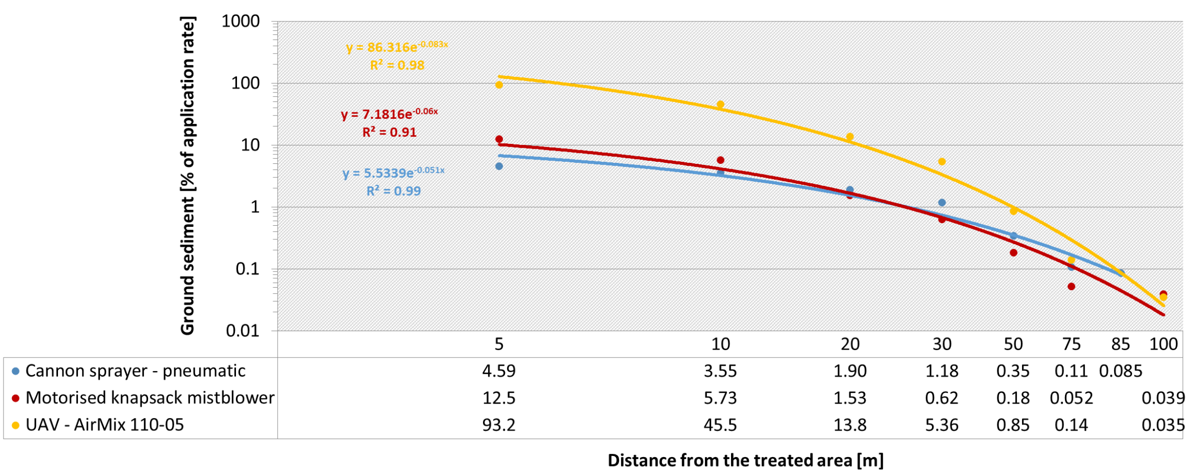
Figure 21: Surface distribution of the ground sediment in percent of the application rate on the trial area "solitary tree" based on median values.



Source: own illustration, JKI

The maximum drift values as ground sediment in percent of application rate per distance are shown in Figure 22. The highest drift values were observed with a UAV. At a distance of 5 m, a drift value of 93.24% was determined. At a distance of 10 m, the drift was reduced by half to 45.54%. At a distance of 100 m, a drift of 0.04% was observed. When using a pneumatic cannon sprayer and a motorised knapsack mistblower, the drift values were significantly lower. At a distance of 5 m and 10 m, the drift values when using a motorised knapsack mistblower were 12.5% and 5.73%, respectively, higher than the drift values when using a pneumatic cannon sprayer, at 4.59% and 3.5%, respectively. However, this changed at the distances of 30, 50, 75, and 85 m (100 m). At these distances, drift of 1.18%, 0.35%, and 0.11% was observed when using a pneumatic cannon sprayer, and drift of 0.62%, 0.18%, and 0.05% was observed when using a motorised knapsack mistblower.

Figure 22: Maximum drift values in percent of the application rate on the trial area “solitary tree”.



Source: own illustration, JKI

The coefficient of determination is 0.91 when using a motorised knapsack sprayer, 0.99 when using a pneumatic cannon sprayer and 0.98 when using a UAV. Values like these show a "perfect model fit". Therefore, the basic drift values were derived from the measured drift values using the exponential regression equation in Figure 22. Table 6 shows these determinate basic drift values as recommended basic drift values for exposure calculations in percent of the application rate on the trial area "solitary tree".

Table 6: Recommended basic drift values for single applications derived from the measured drift values in percent of the application rate on the trial area “solitary tree” based on maximum values.

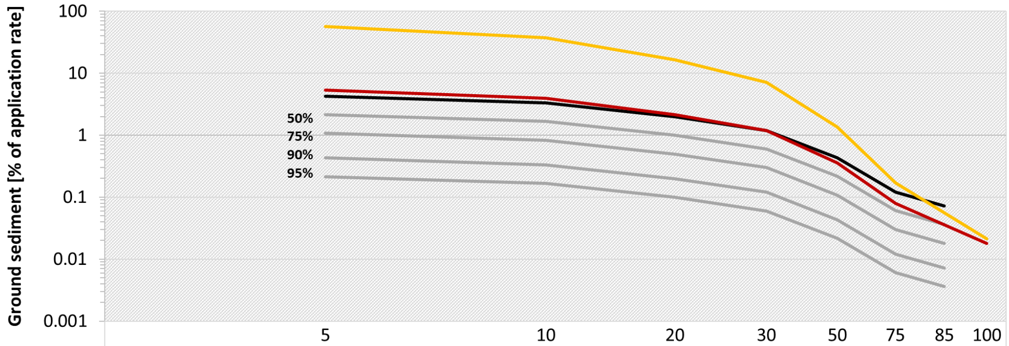
Distance from the treated area [m]	Motorised knapsack mistblower $y = 7.1816\ e^{-0.06\ x}$	Cannon sprayer, pneumatic $y = 5.5339\ e^{-0.051\ x}$	UAV, AirMix 110-05 $y = 86.316\ e^{-0.083\ x}$
5	5.32	4.29	57.0
10	3.94	3.32	37.7
20	2.16	2.00	16.4
30	1.19	1.20	7.16
50	0.36	0.43	1.36
75	0.08	0.12	0.17
85		0.07	
100	0.02		0.02

Source: own compilation, JKI

Drift mitigation classes

Considering the pneumatic cannon sprayer as the standard method, Figure 22 shows the maximum values and drift mitigation classes of the pneumatic cannon sprayer compared to the maximum values of a UAV and a motorised knapsack mistblower. Over the entire measurement range, the maximum drift values of the UAV are higher than the maximum drift values of the pneumatic cannon sprayers. Thus, no drift mitigation is possible with the UAV device compared to the pneumatic cannon sprayer. The maximum drift values of the motorised knapsack mistblower are very close to the maximum drift values of the pneumatic cannon sprayers and even fall below these values at a distance of 50 m. However, there is no undercutting of a drift mitigation class. Thus, no drift mitigation is possible with this application method compared to the pneumatic cannon sprayer.

Figure 23: Maximum value and drift mitigation classes based on drift values on the trial area "solitary tree".



	5	10	20	30	50	75	85	100
Basic value, Cannon sprayer	4.29	3.32	2.00	1.20	0.43	0.12	0.07	
50% drift mitigation	2.14	1.66	1.00	0.60	0.22	0.06	0.04	
75% drift mitigation	1.07	0.83	0.50	0.30	0.11	0.03	0.02	
90% drift mitigation	0.43	0.33	0.20	0.12	0.04	0.01	0.01	
95% drift mitigation	0.21	0.17	0.10	0.06	0.02	0.01	0.00	
UAV - AirMix 110-05	57.0	37.6	16.4	7.16	1.36	0.17		0.02
Motorised knapsack mistblower	5.32	3.94	2.16	1.19	0.36	0.08		0.02

Distance from the treated area [m]

Source: own illustration, JKI

3.2 Drift values on the trial area "avenue"

The trials with the pneumatic cannon sprayer and the helicopter were carried out in the previous project (FKZ 3716 67 404 0). The trials with the hydraulic cannon sprayer were carried out in the current project (FKZ 3719 67 404 0). As the results of both projects will be taken up in the discussion, the main results from the previous project are also shortly summarized here.

Meteorological conditions during the application

For all valid measurements, the mean temperature was below the critical value of 25 °C, the mean air humidity was higher than 30% and the mean wind speed was between 1 m s^{-1} and 5 m s^{-1}. When using a helicopter with ID-120-05 POM, the relative humidity of 39.3% was low but in a valid range. Some additional measurements were excluded if the values were outside the guideline limit for wind direction or for the mean wind speed of 1 m s^{-1} to 5 m s^{-1}. The number of valid measurements for generating basic drift values is given in Table 7. In parentheses, the number of valid measurements for generating drift mitigation measures is given, as for those classifications wind speed must be at least 2 m s^{-1}.

Table 7: Mean values of meteorological conditions during application with a pneumatic and hydraulic cannon sprayer and with a helicopter on the trial area "avenue".

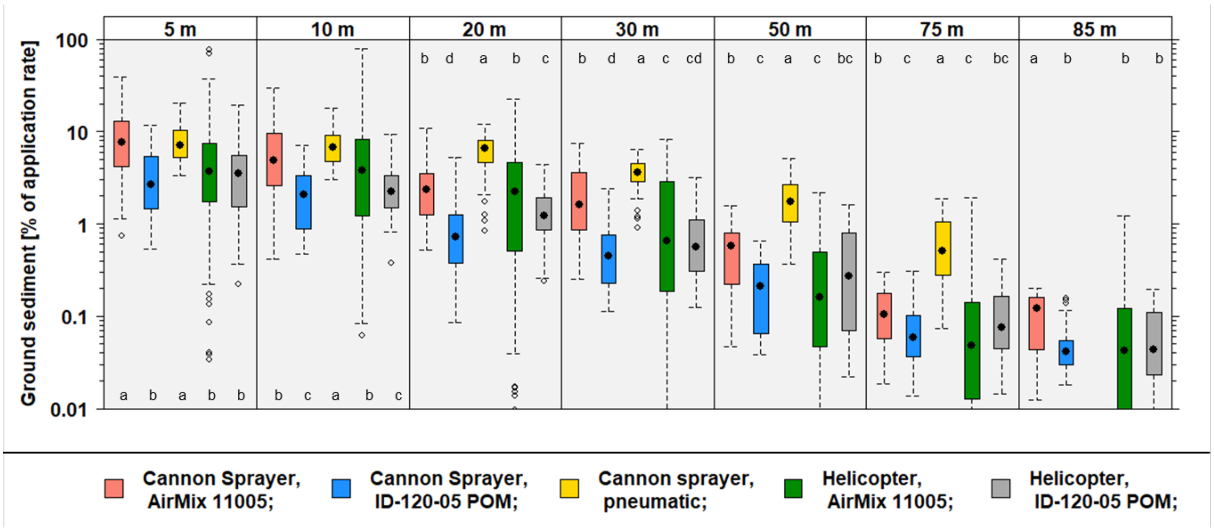
Parameters	Cannon Sprayer						Helicopter			
	pneumatic		AirMix 110-05		ID-120-05 POM		AirMix 110-05		ID-120-05 POM	
Temperature (°C)	20.2	± 0.85	21.8	± 0.52	23.9	± 0.54	19.3	± 1.37	21.3	± 0.31
Relative humidity (%)	68.6	± 2.19	63.2	± 1.37	45.9	± 4.50	47.7	± 4.45	39.2	± 0.99
Wind speed (m s^{-1})	3.22	± 0.56	4.78	± 0.95	4.90	± 0.88	3.92	± 0.98	2.80	± 0.71
Wind direction (°) in relation to the ideal direction	-17.7	± 10.6	-6.78	± 11.4	-5.81	± 22.3	2.22	± 22.3	16.0	± 17.2
Valid measurements	9		4		4		10 (9)		4 (3)	

Source: own compilation, JKI

Measured drift values and recommended basic drift values

When using a pneumatic and a hydraulic cannon sprayer or when using a helicopter, the drift during the treatment of an avenue decreased with increasing distance (Figure 24). At a distance of 5 m to 20 m from the treated area, the measured drift is at a high level, but with clearly significant differences between the devices. At a distance of more than 30 m from the treated area, the differences between the devices become greater. Especially the pneumatic cannon sprayer shows the highest drift values. Furthermore, at a distance of 10 m to 30 m from the treated area, the AirMix 110-05 nozzle shows significantly higher drift values than the ID-120-05 POM nozzle, and this is independent of the device used. At a greater distance from the treated area, the drift values of the AirMix 110-05 decrease to the level of the ID-120-05 POM.

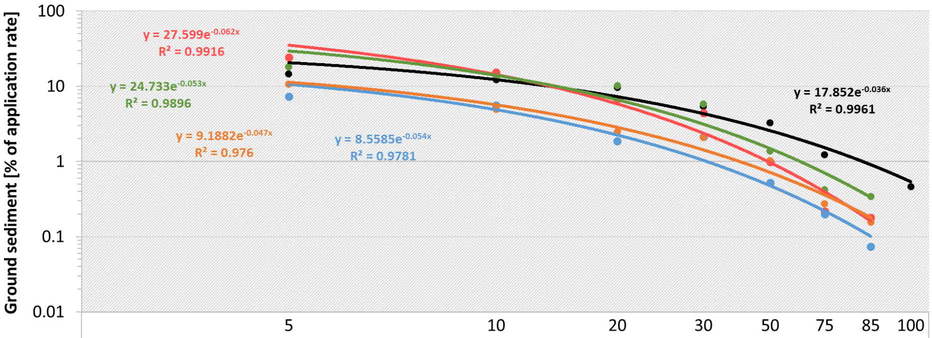
Figure 24: Measured drift values in percent of the application rate on the trial area "avenue" (Median.Test, α = 0.05)



Source: own illustration, JKI

The 90th percentile of the measured drift values is consistent with the observations in Figure 24. Figure 25 shows the 90th percentiles of a pneumatic and hydraulic cannon sprayer and that of a helicopter, both equipped with AirMix 110-05 and ID-120-05 POM. At a distance of 5 m to 30 m from the treated area, no differences are observed between a pneumatic cannon sprayer and a hydraulic cannon sprayer or helicopter, both equipped with the AirMix 110-05 nozzle based on the 90th percentile. After 30 m from the treated area, the drift values of the AirMix 110-05 dropped to the level of the ID-120-05 POM for both devices. In contrast, the ID-120-05 POM nozzle shows the lowest drift values over the entire measuring area, regardless of the device used. For the application with a helicopter, the values from the report of the previous project differ, as the values had to be recalculated due to an incorrect flying speed.

Figure 25: 90th percentile of drift values in percent of the application rate on the trial area "avenue".



	5	10	20	30	50	75	85	100
● Cannon sprayer - pneumatic	14.5	12.1	9.55	5.39	3.28	1.22		0.46
● Cannon sprayer - AirMix 110-05	24.2	15.3	6.75	4.43	1.00	0.22	0.18	
● Cannon sprayer - ID-120-05 POM	7.29	5.62	1.87	2.13	0.53	0.20	0.07	
● Helicopter - AirMix 110-05	18.3	13.8	10.2	5.81	1.37	0.42	0.34	
● Helicopter - ID-120-05 POM	10.6	4.92	2.51	2.08	1.03	0.27	0.16	

Distance from the treated area [m]

Source: own illustration, JKI

Derived from the function of the regression curve, the basic drift values were calculated and are shown in Table 8. The very low basic drift values of the ID-120-05 POM nozzle are striking, regardless of the device. With the ID-120-05 POM, the base drift values are up to three times lower than with the AirMix 110-05 or with the pneumatic cannon sprayer. If an application was to take place two or three times in the season, Table 9 and Table 10 show the drift values based on the 82nd and 77th percentiles for the risk assessment of the respective products.

Table 8: Recommended basic drift values for single application derived from the measured drift values in percent of the application rate on the trial area "avenue" based on 90th percentile.

Distance from the treated area [m]	Cannon Sprayer			Helicopter	
	pneumatic $y = 17.852e^{-0.036x}$	AirMix 110-05 $y = 27.599e^{-0.062x}$	ID-120-05 POM $y = 8.559e^{-0.054x}$	AirMix 110-05 $y = 24.733e^{-0.053x}$	ID-120-05 POM $y = 9.188e^{-0.047x}$
5	14.91	20.24	6.53	18.98	7.26
10	12.45	14.85	4.99	14.56	5.74
20	8.69	7.99	2.91	8.57	3.59
30	6.06	4.30	1.69	5.04	2.24
50	2.95	1.24	0.58	1.75	0.88

Distance from the treated area [m]	Cannon Sprayer			Helicopter	
	pneumatic $y = 17.852e^{-0.036x}$	AirMix 110-05 $y = 27.599e^{-0.062x}$	ID-120-05 POM $y = 8.559e^{-0.054x}$	AirMix 110-05 $y = 24.733e^{-0.053x}$	ID-120-05 POM $y = 9.188e^{-0.047x}$
75	1.20	0.26	0.15	0.46	0.27
85		0.14	0.09	0.27	0.17
100	0.49				

Source: own compilation, JKI

Table 9: Recommended basic drift values for twice application derived from the measured drift values in percent of the application rate on the trial area "avenue" based on 82nd percentile.

Distance from the treated area [m]	Cannon Sprayer			Helicopter	
	pneumatic $y = 15.343e^{-0.035x}$	AirMix 110-05 $y = 14.976e^{-0.05x}$	ID-120-05 POM $y = 6.151e^{-0.054x}$	AirMix 110-05 $y = 16.062e^{-0.055x}$	ID-120-05 POM $y = 7.736e^{-0.048x}$
5	12.88	11.66	4.70	12.20	6.09
10	10.81	9.08	3.58	9.27	4.79
20	7.62	5.51	2.09	5.35	2.96
30	5.37	3.34	1.22	3.08	1.83
50	2.67	1.23	0.41	1.03	0.70
75	1.11	0.35	0.11	0.26	0.21
85		0.21	0.06	0.15	0.13
100	0.46				

Source: own compilation, JKI

Table 10: Recommended basic drift values for triple application derived from the measured drift values in percent of the application rate on the trial area "avenue" based on 77th percentile.

Distance from the treated area [m]	Cannon Sprayer			Helicopter	
	pneumatic $y = 13.711e^{-0.034x}$	AirMix 110-05 $y = 13.187e^{-0.05x}$	ID-120-05 POM $y = 5.303e^{-0.054x}$	AirMix 110-05 $y = 13.298e^{-0.057x}$	ID-120-05 POM $y = 5.868e^{-0.046x}$
5	11.57	10.27	4.05	10.00	4.66
10	9.76	8.00	3.09	7.52	3.70
20	6.95	4.85	1.80	4.25	2.34
30	4.94	2.94	1.05	2.41	1.48
50	2.50	1.08	0.36	0.77	0.59
75	1.07	0.31	0.09	0.19	0.19

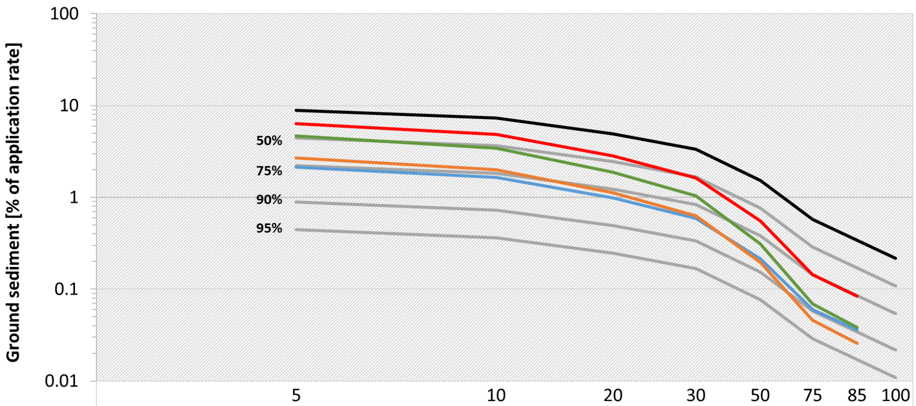
Distance from the treated area [m]	Cannon Sprayer			Helicopter	
	pneumatic y = 13.711e $^{-0.034x}$	AirMix 110-05 y = 13.187e $^{-0.05x}$	ID-120-05 POM y = 5.303e $^{-0.054x}$	AirMix 110-05 y = 13.298e $^{-0.057x}$	ID-120-05 POM y = 5.868e $^{-0.046x}$
85		0.19	0.05	0.10	0.12
100	0.46				

Source: own compilation, JKI

Drift mitigation classes

Figure 25 shows the adjusted median of the pneumatic cannon sprayer as a baseline and the derived drift mitigation classes of 50%, 75%, 90% and 95% compared to the adjusted median of the hydraulic cannon sprayer and the helicopter with AirMix 110-05 and ID-120-05 POM nozzles. When using a cannon sprayer with AirMix 110-05, no drift mitigation is to be defined as not falling below the 50% drift mitigation class over the entire distance. When using a helicopter with AirMix 110-05 and ID-120-05 POM nozzles, a drift mitigation of 50% is possible, as this class is undercut over the entire distance. When using a pneumatic cannon sprayer with ID-120-05 POM, a drift mitigation of 75% is even possible, as this class is undercut over the entire distance.

Figure 26: Median value and drift mitigation classes based on drift values on the trial area "avenue".



	5	10	20	30	50	75	85	100
Basis value, Cannon sprayer - pneumatic	8.87	7.30	4.94	3.35	1.53	0.58		0.22
50% drift mitigation	4.44	3.65	2.47	1.67	0.77	0.29		0.11
75% drift mitigation	2.22	1.83	1.24	0.84	0.38	0.14		0.05
90% drift mitigation	0.89	0.73	0.49	0.33	0.15	0.06		0.02
95% drift mitigation	0.44	0.37	0.25	0.17	0.08	0.03		0.01
Cannon sprayer - AirMix 110-05	6.33	4.83	2.81	1.64	0.56	0.14	0.08	
Cannon sprayer - ID-120-05 POM	2.13	1.65	0.99	0.59	0.21	0.06	0.04	
Helicopter - AirMix 110-05	4.65	3.44	1.89	1.04	0.31	0.07	0.04	
Helicopter- ID-120-05 POM	2.67	2.00	1.12	0.63	0.20	0.05	0.03	

Distance from the treated area [m]

Source: own illustration, JKI

3.3 Drift values on the trial area "forest edge"

The trials with the pneumatic cannon sprayer were carried out in the previous project (FKZ 3716 67 404 0). The trials with the helicopter were carried out in the current project (FKZ 3719 67 404 0). As the results of both projects will be taken up in the discussion, the main results from the previous project are also shortly summarized here.

Meteorological conditions during the application

The meteorological conditions during the treatment of a forest edge largely corresponded to the JKI guideline (JKI 2013b). The mean wind speed during the trials ranged between 2.26 m s^{-1} to 3.63 m s^{-1}, the mean air temperature ranged from 16.4 °C to 21.3 °C and was below the critical value of 25 °C. The mean relative air humidity ranged from 52.0% to 73.7% (Table 11).

Table 11: Mean values of meteorological conditions during the application with a pneumatic cannon sprayer and with a helicopter on the trial area "forest edge".

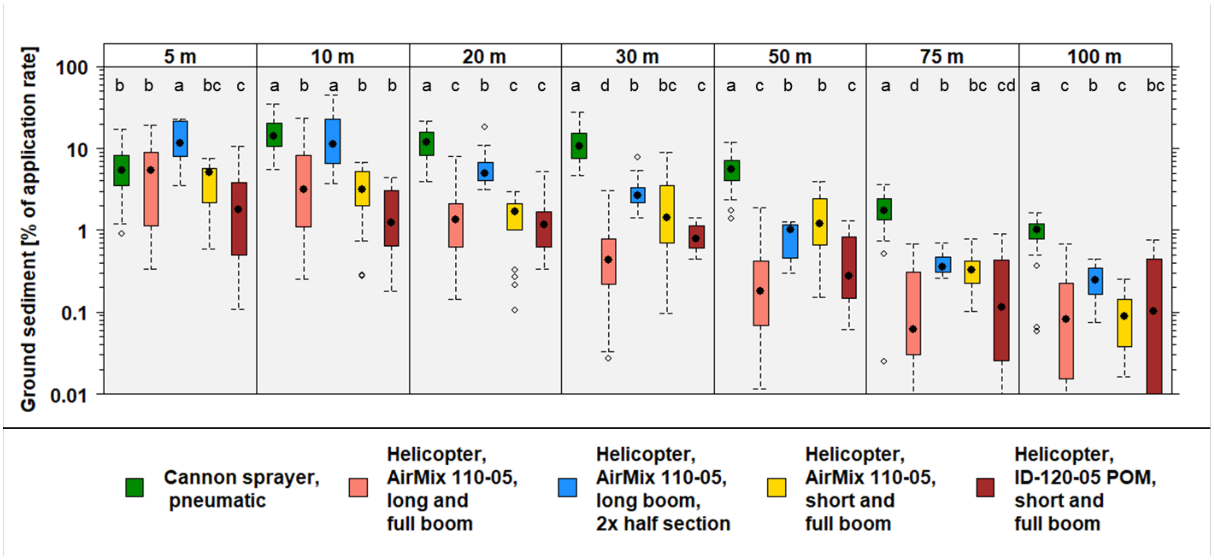
Parameters	Cannon sprayer, pneumatic		Helicopter							
			AirMix 110-05 long and full boom		AirMix 110-05 long boom, 2x half section		ID-120-05 POM short and full boom		AirMix 110-05 short and full boom	
Temperature [°C]	16.4	± 1.04	19.7	± 0.69	21.0	± 0.27	21.0	± 0.05	21.3	± 0.81
Relative humidity [%]	73.7	± 4.22	60.0	± 1.77	54.3	± 0.66	53.9	± 3.19	52.0	± 3.42
Wind speed [m s^{-1}]	3.63	± 1.03	2.48	± 0.86	3.43	± 0.97	3.17	± 0.48	2.26	± 0.41
Wind direction [°] in relation to ideal direction	4.56	± 19.5	-0.39	± 24.7	17.7	± 27.2	11.4	± 0.92	11.0	± 0.26
Valid measurements	7		3		2		2		2	

Source: own compilation, JKI

Measured drift values and recommended basic drift values

The measured drift values as ground sediment on the trial area "forest edge" are shown in Figure 27. In all measurements with the helicopter, the drift decreases with increasing distance. Thereby, the values of AirMix 110-05 long and full boom and ID-120-05 POM short and full boom decreased faster than AirMix 110-05 long and two half sections and AirMix 110-05 short and full boom. With the pneumatic cannon sprayer, the drift initially increases up to a distance of 20 m and then decreases with increasing distance. As already explained in the report of the previous project, this is related to the wind direction and the application direction. In order to represent a worst case situation, the maximum value of the 90th percentile of the three distances 5 m, 10 m and 20 m was taken into account as drift value in the subsequent calculation of the basic drift values. In the next step, the 90th percentiles were calculated and the devices, nozzles and application variants were compared with each other (Figure 28).

Figure 27: Measured drift values in percent of the application rate on the trial area "forest edge" (Median.Test, α = 0.05)



Source: own illustration, JKI

<u>Comparison 1: pneumatic cannon sprayer vs. helicopter AirMix 110-05 with long and full boom and with long boom and 2x half boom sections</u>

When treating the forest edge with a helicopter and a full boom (red line), lower drift values were found over all distances than with a pneumatic cannon sprayer (Figure 28). When treating a forest edge with half a boom twice (blue line), drift values similar to those of a pneumatic cannon sprayer were found at a distance of 5 m from the treated area. With increasing distance from the treated area, the drift values of the helicopter with half boom decreased more and approached the 90th percentile of the helicopter with full boom.

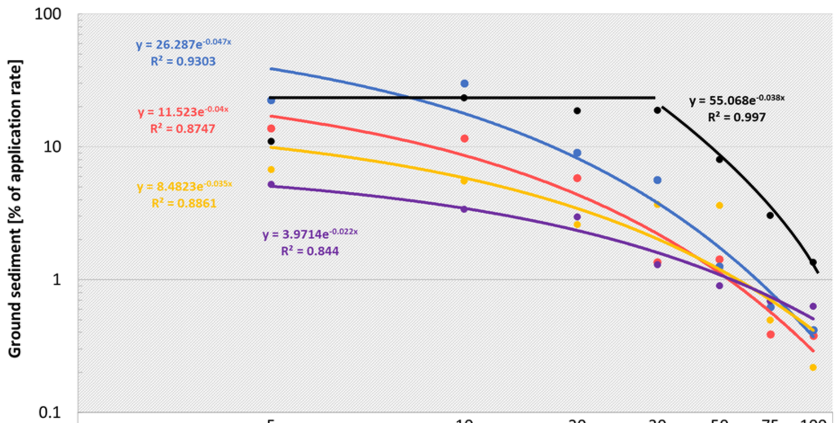
<u>Comparison 2: pneumatic cannon sprayer vs. helicopter AirMix 110-05 with long and full boom and with short and full boom</u>

In these studies, too, the measured drift values decrease with increasing distance from the treated area. Both helicopter variants, long and full boom (red line) and short and full boom (yellow line), also show significantly lower drift values than the pneumatic cannon sprayer (Figure 28). It is noticeable that the 90th percentile of the two helicopter variants differs only slightly from each other in these studies. The influence of the boom length on the drift can thus be assessed as low.

<u>Comparison 3: pneumatic cannon sprayer vs. helicopter AirMix 110-05 short and full boom and with ID-120-05 POM short and full boom</u>

The treatment of a forest edge with a helicopter and ID-120-05 POM nozzles (purple lines) showed by far the lowest drift values (Figure 28). Compared to a helicopter with AirMix 110-05 nozzles (yellow line), the drift with the ID-120-05 POM nozzles was significantly lower, especially in the close range up to 30 m from the treated area. From a distance of 50 m to the treated area, the AirMix 110-05 approached the drift level of the ID-120-05 POM nozzle. However, both variants show significantly lower drift than a pneumatic cannon sprayer.

Figure 28: 90th percentile of the measured drift values in percent of the application rate on the trial area “forest edge”.



	5	10	20	30	50	75	100
Cannon sprayer, pneumatic	11.02	23.41	18.66	18.78	8.04	3.05	1.35
Helicopter - AirMix 110-05, long and full boom	13.79	11.61	5.84	1.36	1.42	0.39	0.38
Helicopter - AirMix 110-05, long boom, 2x half sections	22.44	30.00	9.03	5.65	1.26	0.62	0.42
Helicopter - AirMix 110-05, short and full boom	6.76	5.52	2.61	3.68	3.62	0.50	0.22
Helicopter - ID-120-05 POM, short and full boom	5.21	3.40	2.98	1.29	0.90	0.69	0.63

Distance from the treated area [m]

Source: own illustration, JKI

The recommended basic drift values derived from the regression curves are shown in Table 12. As described above, the values were adjusted for use with a pneumatic cannon sprayer in close range of the treated area. For 5, 10 and 20 m, the maximum value of the 90th percentile was given as the basic drift value. For distances above 30 m, a regression line was calculated and the basic drift values derived from it. If an application was to take place two or three times in the season, Table 13 and Table 14 show the drift values based on the 82nd and 77th percentiles for the risk assessment of the respective products.

Table 12: Recommended basic drift values for single application derived from the measured drift values in percent of the application rate on the trial area “forest edge” based on 90th percentile.

Distance from the treated area [m]	Cannon sprayer pneumatic, $y = 55.068e^{-0.038x}$	Helicopter AirMix 110-05 long and full boom, $y = 11.523e^{-0.04x}$	Helicopter AirMix 110-05 long boom, 2x half sections $y = 26.287e^{-0.047x}$	Helicopter AirMix 110-05 short and full boom $y = 8.4823e^{-0.035x}$	Helicopter ID-120-05 POM short and full boom $y = 3.9714e^{-0.022x}$
5	23.41 *	9.43	20.78	7.12	3.56
10	23.41 *	7.72	16.43	5.98	3.19
20	23.41 *	5.12	10.27	4.21	2.56
30	17.61	3.47	6.42	2.97	2.05
50	8.24	1.56	2.51	1.47	1.32
75	3.19	0.57	0.77	0.61	0.76
100	1.23	0.21	0.2	0.26	0.44

* Maximum value of the 90th percentile in the distance range 5 to 20 m is used for basic drift values. The exponential regression equation to derivate basic drift value is used for the distances from 30 to 100 m.
Source: own compilation, JKI

Table 13: Recommended basic drift values for twice application derived from the measured drift values in percent of the application rate on the trial area "forest edge" based on 82nd percentile.

Distance from the treated area [m]	Cannon sprayer pneumatic, $y = 47.172e^{-0.037x}$	Helicopter AirMix 110-05 long and full boom, $y = 9.81e^{-0.041x}$	AirMix 110-05 long boom, 2x half sections $y = 22.005e^{-0.046x}$	AirMix 110-05 short and full boom $y = 7.978e^{-0.035x}$	ID-120-05 POM short and full boom $y = 3.083e^{-0.021x}$
5	21.46*	7.99	17.48	6.70	2.78
10	21.46*	6.51	13.89	5.62	2.50
20	21.46*	4.32	8.77	3.96	2.03
30	15.55	2.87	5.54	2.79	1.64
50	7.42	1.26	2.21	1.39	1.08
75	2.94	0.45	0.70	0.58	0.64
100	1.17	0.16	0.22	0.24	0.38

* Maximum value of the 90th percentile in the distance range 5 to 20 m is used for basic drift values. The exponential regression equation to derivate basic drift value is used for the distances from 30 to 100 m.
Source: own compilation, JKI

Table 14: Recommended basic drift values for triple application derived from the measured drift values in percent of the application rate on the trial area "forest edge" based on 77th percentile.

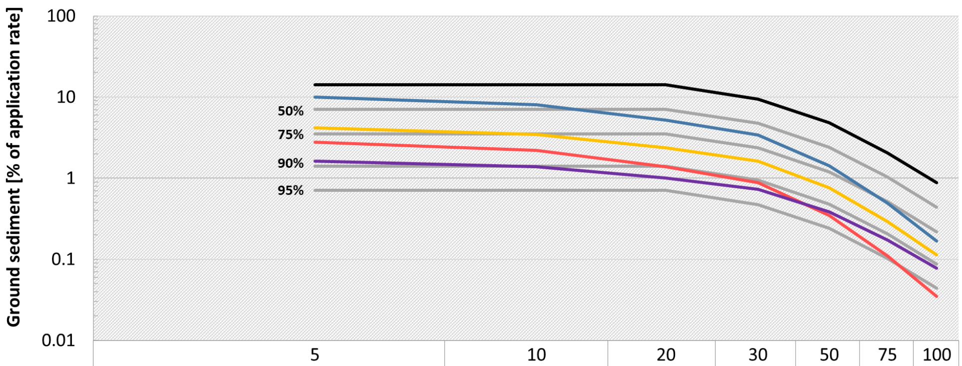
Distance from the treated area [m]	Cannon sprayer pneumatic, $y = 44.957e^{-0.037x}$	Helicopter AirMix 110-05 long and full boom, $y = 6.447e^{-0.039x}$	AirMix 110-05 long boom, 2x half sections $y = 20.676e^{-0.046x}$	AirMix 110-05 short and full boom $y = 7.759e^{-0.037x}$	ID-120-05 POM short and full boom $y = 3.073e^{-0.022x}$
5	20.78	5.30	16.43	6.45	2.75
10	20.78	4.36	13.05	5.36	2.47
20	20.78	2.96	8.24	3.70	1.98
30	14.82	2.00	5.20	2.56	1.59
50	7.07	0.92	2.07	1.22	1.02
75	2.80	0.35	0.66	0.48	0.59
100	1.11	0.13	0.21	0.19	0.34

* Maximum value of the 90th percentile in the distance range 5 to 20 m is used for basic drift values. The exponential regression equation to derivate basic drift value is used for the distances from 30 to 100 m.
Source: own compilation, JKI

Drift mitigation classes

Figure 29 shows the adjusted median of the pneumatic cannon sprayer as a baseline and the derived drift mitigation classes of 50%, 75%, 90% and 95% compared to the adjusted median of the helicopter with two different nozzles and boom lengths. When treating a forest edge with a helicopter with AirMix 110-05 and short and full boom (yellow line), a drift mitigation of 50% is observed. Although the median falls below the 75% drift mitigation class after a distance of 10 m from the treated area, the classification of the drift mitigation is based on the classes that are undercut throughout the entire measurement range. Thus, using a helicopter AirMix 110-05 with a long and full boom (red line) and a helicopter ID-120-05 POM with short boom and full boom (purple line), a drift mitigation of 75% is possible in contrast to a pneumatic cannon sprayer.

Figure 29: Median value and drift mitigation classes based on drift values on the trial area "forest edge".



	5	10	20	30	50	75	100
Basic value - Cannon sprayer, pneumatic	14.1	14.1	14.1	9.50	4.81	2.06	0.88
50% drift mitigation	7.06	7.06	7.06	4.75	2.41	1.03	0.44
75% drift mitigation	3.53	3.53	3.53	2.37	1.20	0.51	0.22
90% drift mitigation	1.41	1.41	1.41	0.95	0.48	0.21	0.09
95% drift mitigation	0.71	0.71	0.71	0.47	0.24	0.10	0.04
Helicopter - AirMix 110-05, long boom, 2x sections	9.93	8.01	5.21	3.39	1.43	0.49	0.17
Helicopter - AirMix 110-05, long boom	2.77	2.20	1.39	0.88	0.35	0.11	0.04
Helicopter - AirMix 110-05, short boom	4.21	3.48	2.38	1.63	0.76	0.29	0.11
Helicopter - ID-120-05 POM, short boom	1.62	1.38	1.01	0.73	0.38	0.17	0.08

Distance from the treated area [m]

Source: own illustration, JKI

3.4 Drift values on the trial area "container"

The trials with the knapsack sprayer on the trial area “container” were carried out in the current project (FKZ 3719 67 404 0). These trials were divided into application on the foundation against crawling insects and application on a wall against flying insects.

3.4.1 Application on foundation against crawling insects

Meteorological conditions during the application

The mean air temperature ranged from 15.4 °C to 19.5 °C and was below the critical value of 25 °C, the mean relative air humidity ranged from 45.7% to 60.3% and the mean wind speed during the trials ranged between 1.9 m s^{-1} to 2.7 m s^{-1} (Table 15). These values correspond to the

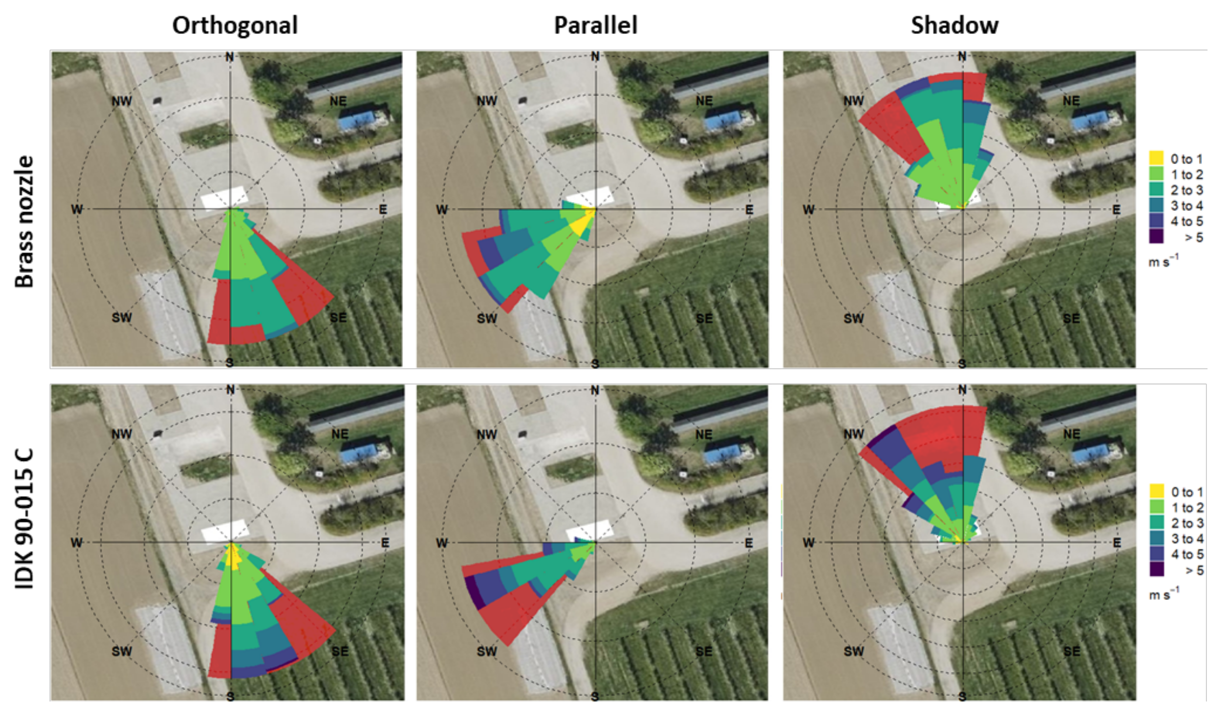
JKI guideline 7-1.5 (JKI 2013d). Trials outside the limits were not evaluated. Figure 30 shows the wind direction and wind speed of the evaluated trials divided into the wind direction orthogonal, parallel and shadow.

Table 15: Mean values of meteorological conditions during foundation application against crawling insects with a knapsack sprayer on the trial area "container".

Parameters	Orthogonal				Parallel				Shadow			
	Brass nozzle		IDK 90-015 C		Brass nozzle		IDK 90-015 C		Brass nozzle		IDK 90-015 C	
Temperature [°C]	18.3	± 3.6	17.8	± 4.8	19.3	± 1.0	19.5	± 0.8	15.4	± 3.7	16.4	± 4.6
Relative humidity [%]	60.3	± 7.7	57.0	± 3.3	59.2	± 8.9	56.9	± 7.8	45.7	± 4.9	48.4	± 5.9
Wind speed [m s-1]	1.9	± 0.3	2	± 1.1	2.1	± 0.9	2.7	± 1.0	1.9	± 0.8	2.5	± 1.2
Wind direction [°] in relation to ideal direction	-0.6	± 30.4	6.1	± 23.6	5.0	± 22.1	8.3	± 18.7	2.0	± 29.3	-2.2	± 39.6
Valid measurements	6		5		7		7		5		5	

Source: own compilation, JKI

Figure 30: Wind direction and wind speed during foundation application against crawling insects with a knapsack sprayer on the trial area "container".



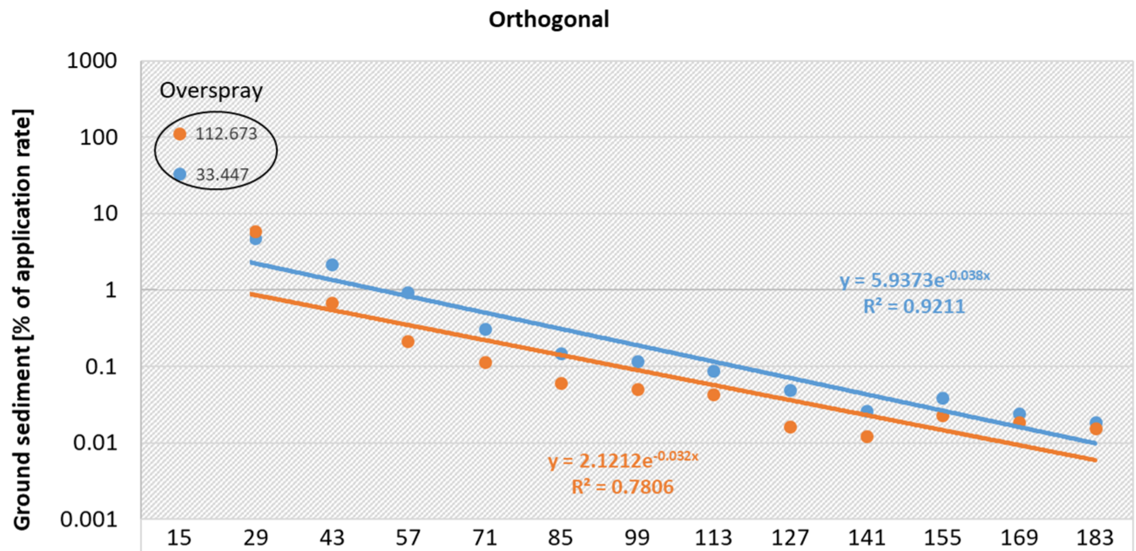
Source: own illustration, JKI

Drift values and recommended basic drift values

The following 3 figures show the 90th percentiles of the measured drift values as ground sediment in percentage of the application rate during foundation application at the trial area "container" with orthogonal (Figure 31) and parallel wind direction (Figure 32), as well as in the wind shadow (Figure 33). For all three wind directions, the drift decreases continuously over the entire measuring area with increasing distance from the treated area. The first collector at 15 cm was declared as overspray for all three wind directions and is not included in the evaluation, as it cannot be determined whether the collectors were sprayed during application or whether it was a rebound from the wall.

With an orthogonal wind direction, higher drift values were observed with the brass nozzle than with the IDK 90-015 C nozzle. At a distance of 57 cm from the treated area, 0.93% drift was measured with the brass nozzle and only 0.211% drift with the IDK 90-015 C nozzle (Figure 31). With parallel wind direction, the measured values were overall at a higher level than with orthogonal wind direction. At a distance of 57 cm, the drift values were 4.64% with the brass nozzle and 4.87% with the IDK 90-015 C nozzle. Over the entire measuring range, the brass nozzle produced only slightly higher drift values than the IDK 90-015 C nozzle (Figure 32). This contrasts with the drift values when used in the shadow of the wind. If there would be no wind, the drift values of the IDK 90-015 C nozzle decrease faster with increasing distance from the treated areas than with the brass nozzle. Nevertheless, the drift values in the shadow of the wind are higher than with orthogonal wind direction. Thus, in the case of wind shadow at a distance of 57 cm from the treated surface, a drift of 7.72% was observed with the brass nozzle and of 4.09% with the IDK 90-015 C nozzle (Figure 33).

Figure 31: 90th percentile of the measured drift values in percent of the application rate during foundation application on the trial area "container" at orthogonal wind direction.

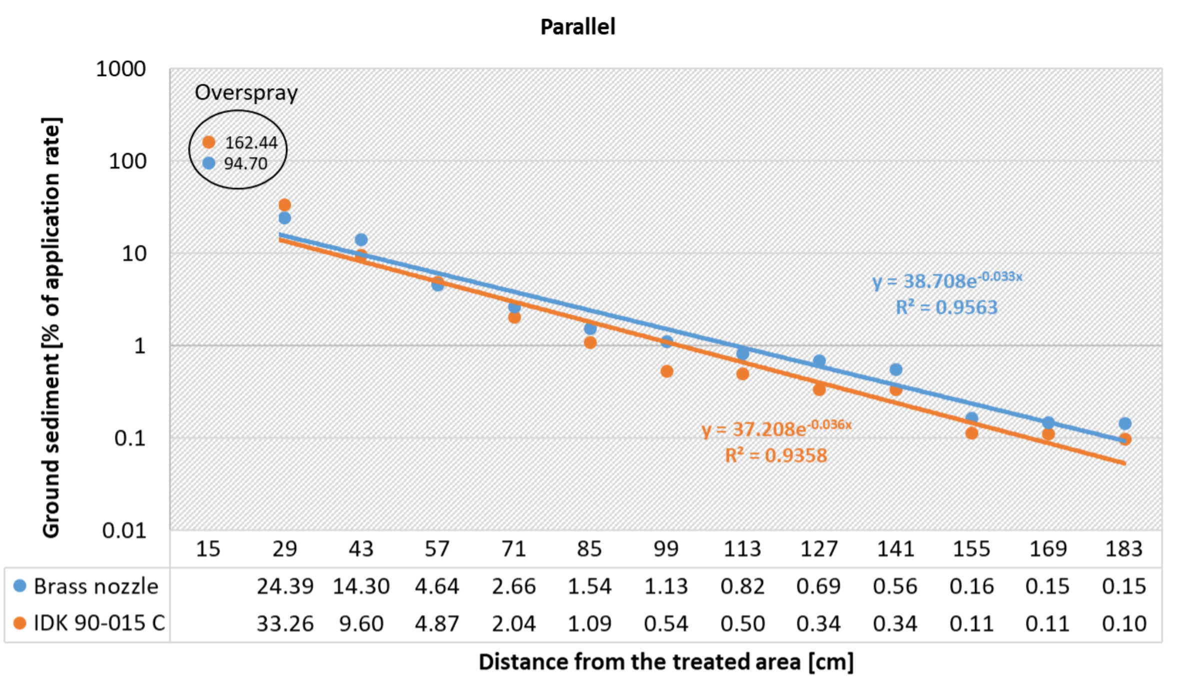


	15	29	43	57	71	85	99	113	127	141	155	169	183
Brass nozzle		4.684	2.163	0.930	0.311	0.150	0.118	0.089	0.050	0.026	0.039	0.024	0.018
IDK 90-015 C		5.799	0.667	0.211	0.116	0.060	0.051	0.043	0.016	0.012	0.023	0.019	0.015

Distance from the treated area [cm]

Source: own illustration, JKI

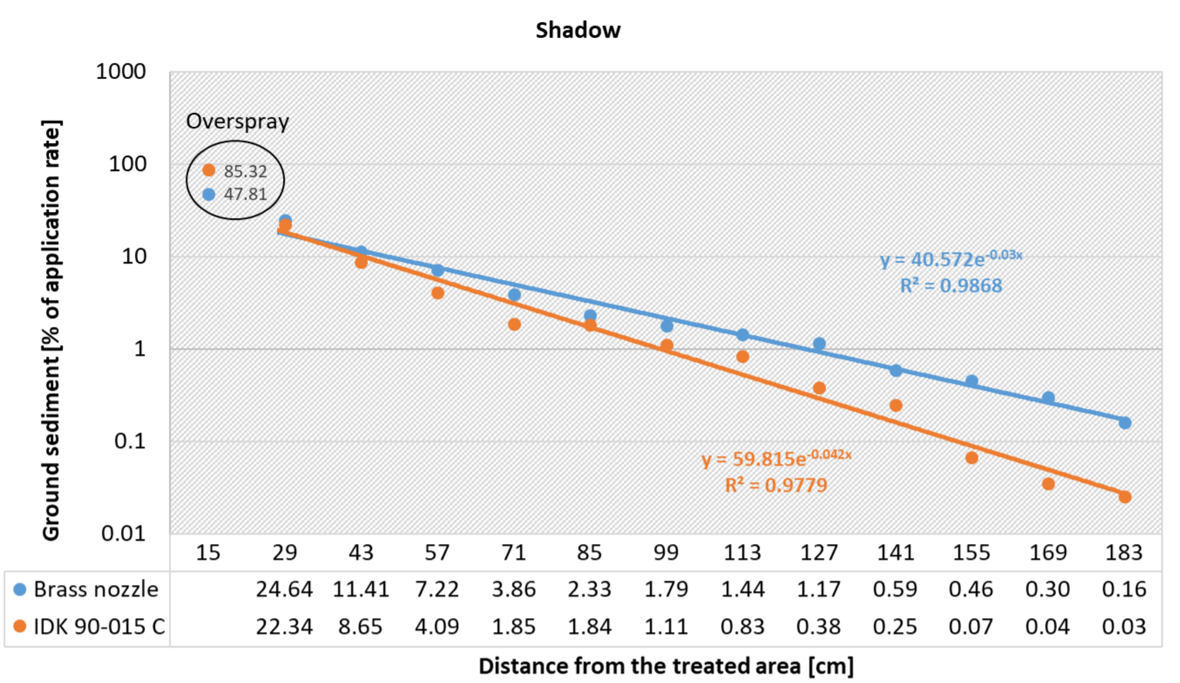
Figure 32: 90th percentile of the measured drift values in percent of the application rate during foundation application on the trial area "container" at parallel wind direction.



	15	29	43	57	71	85	99	113	127	141	155	169	183
Brass nozzle		24.39	14.30	4.64	2.66	1.54	1.13	0.82	0.69	0.56	0.16	0.15	0.15
IDK 90-015 C		33.26	9.60	4.87	2.04	1.09	0.54	0.50	0.34	0.34	0.11	0.11	0.10

Source: own illustration, JKI

Figure 33: 90th percentile of the measured values of the drift in percent of the application rate during foundation application on the trial area "container" in the wind shadow.



	15	29	43	57	71	85	99	113	127	141	155	169	183
Brass nozzle		24.64	11.41	7.22	3.86	2.33	1.79	1.44	1.17	0.59	0.46	0.30	0.16
IDK 90-015 C		22.34	8.65	4.09	1.85	1.84	1.11	0.83	0.38	0.25	0.07	0.04	0.03

Source: own illustration, JKI

Table 16 shows the recommended basic drift values when treating a house wall with a chemical barrier of 50 cm to control crawling insects with a knapsack sprayer in different wind directions. These basic drift values were derived from the measured values using the regression line. The lowest basic drift values were observed with orthogonal wind direction using an IDK 90-015 C nozzle, followed by parallel wind direction and treatment of the house wall in the wind shadow.

Table 16: Recommended basic drift values for single application derived from the measured drift values in percent of the application rate during foundation application on the trial area "container" based on 90th percentile.

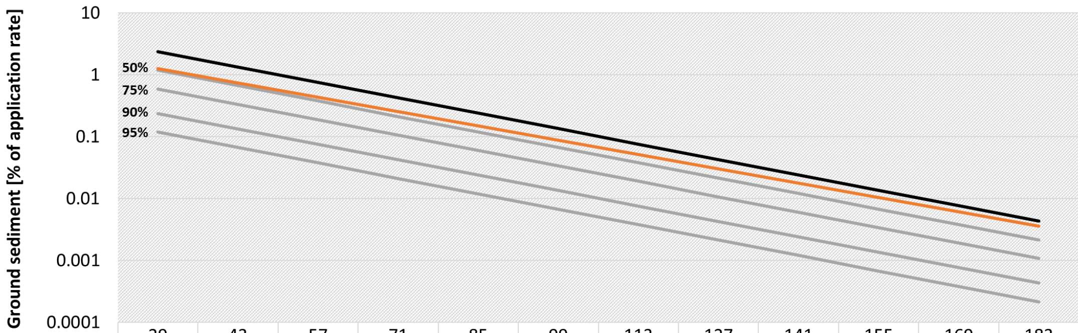
Distance [cm]	Orthogonal		Parallel		Shadow	
	Brass nozzle	IDK 90-015 C	Brass nozzle	IDK 90-015 C	Brass nozzle	IDK 90-015 C
	$y = 5.9373\ e^{-0.038x}$	$y = 2.1212\ e^{-0.032x}$	$y = 38.708\ e^{-0.033x}$	$y = 37.208\ e^{-0.036x}$	$y = 40.572\ e^{-0.03x}$	$y = 59.815\ e^{-0.042x}$
29	1.972	0.839	14.87	13.10	17.00	17.69
43	1.159	0.536	9.37	7.91	11.17	9.83
57	0.681	0.342	5.90	4.78	7.34	5.46
71	0.400	0.219	3.72	2.89	4.82	3.03
85	0.235	0.140	2.34	1.74	3.17	1.68
99	0.138	0.089	1.48	1.05	2.08	0.94
113	0.081	0.057	0.93	0.64	1.37	0.52
127	0.048	0.036	0.59	0.38	0.90	0.29
141	0.028	0.023	0.37	0.23	0.59	0.16
155	0.016	0.015	0.23	0.14	0.39	0.09
169	0.010	0.010	0.15	0.08	0.25	0.05
183	0.006	0.006	0.09	0.05	0.17	0.03

Source: own compilation, JKI

Drift mitigation measures

The trial design is a two-factor trial design with the factors nozzle and wind direction. The analysis of the drift values showed that there was no interaction between the factors. Therefore, the factors can also be considered separately. Figure 34 shows the drift reduction classes according to JKI Guideline 2-2.1 over all three wind directions based on the adjusted medians of the brass nozzle and, in comparison, the adjusted medians of the IDK 90-015 C nozzle. Over the entire measuring range, the IDK 90-015 C nozzle does not fall below the 50% drift mitigation class. Thus, no drift mitigation can be detected with the IDK 90-015 C nozzle at a foundation application of 50 cm. In contrast, Figure 35 shows the measured drift values as a percentage of the application rate at the trial area "container" over the two nozzles as a function of the wind direction. Clearly lower drift values were observed with an orthogonal wind direction than with the other two wind directions. This difference is significant over the entire measuring area. Thus, considering the wind direction is an important parameter to mitigate environmental risks due to drift in this application.

Figure 34: Median value and drift mitigation classes based on drift values on the trial area "container" for foundation application.

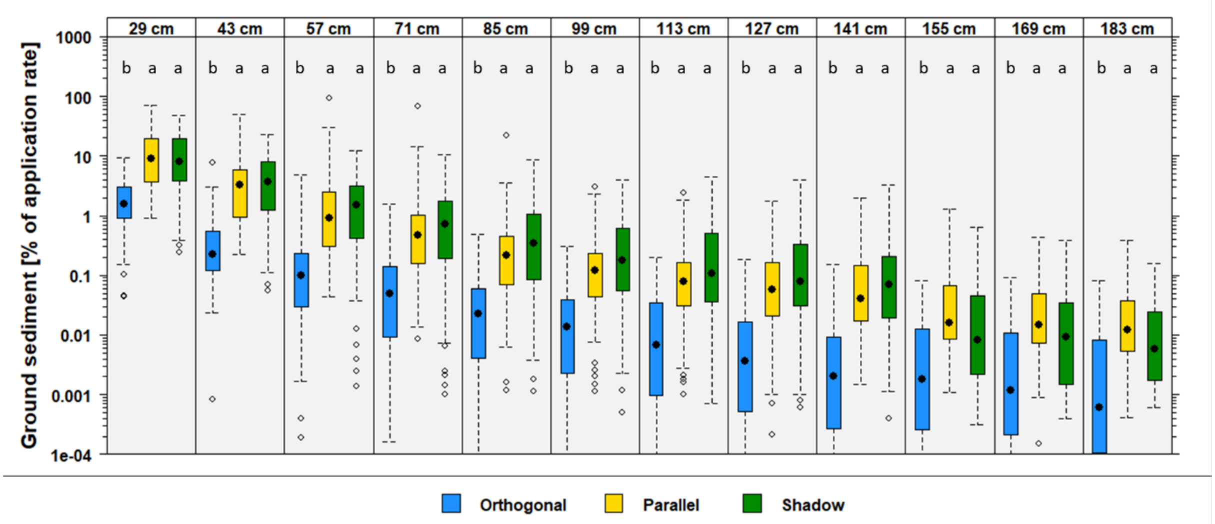


	29	43	57	71	85	99	113	127	141	155	169	183
Basis value, Brass nozzle	2.38	1.34	0.76	0.43	0.24	0.13	0.076	0.043	0.024	0.014	0.0077	0.0043
50% drift mitigation	1.19	0.67	0.38	0.21	0.12	0.067	0.038	0.021	0.012	0.0068	0.0038	0.0022
75% drift mitigation	0.59	0.34	0.19	0.11	0.060	0.034	0.019	0.011	0.0060	0.0034	0.0019	0.0011
90% drift mitigation	0.24	0.13	0.076	0.043	0.024	0.013	0.0076	0.0043	0.0024	0.0014	0.00077	0.00043
95% drift mitigation	0.12	0.067	0.038	0.021	0.012	0.0067	0.0038	0.0021	0.0012	0.00068	0.00038	0.00022
IDK 90-015 C	1.26	0.74	0.43	0.25	0.15	0.088	0.052	0.030	0.018	0.010	0.0061	0.0036

Distance from the treated area [cm]

Source: own illustration, JKI

Figure 35: Measured drift values in percent of the application rate during foundation application on the trial area "container" as a function of the wind direction (Median.Test, α = 0.05).



Source: own illustration, JKI

3.4.2 Application on a wall against flying insects

Meteorological conditions during the application

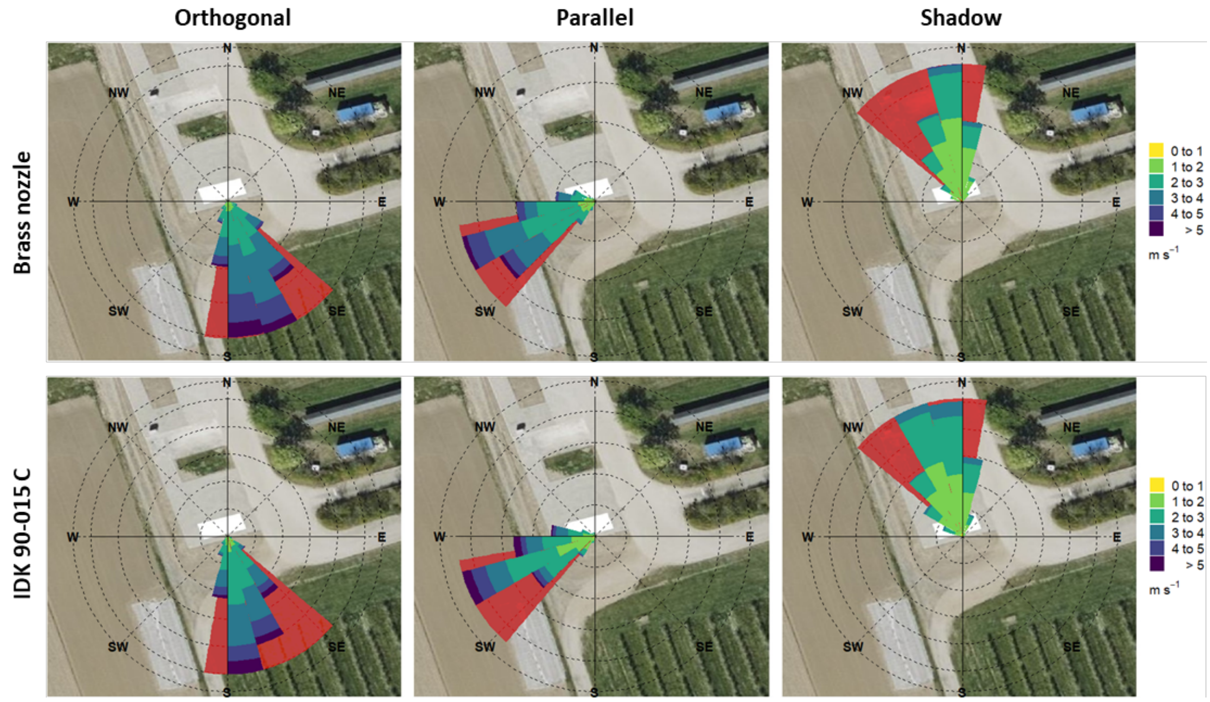
During the trials, the mean air temperature ranged between 10.0 °C and 19.8 °C, which is below the critical value of 25 °C. The mean relative humidity was between 45.2% and 58.9% and the mean wind speed between 1.9 m s^{-1} and 3.2 m s^{-1} (Table 17). These values correspond to JKI guideline 7-1.5 (JKI 2013b). Trials outside the limits were not evaluated. Figure 36 shows the wind direction and wind speed of the evaluated trials divided into the wind directions orthogonal, parallel and shadow.

Table 17: Mean values of meteorological conditions during house wall application against flying insects with a knapsack sprayer on the trial area "container".

Parameters	Orthogonal				Parallel				Shadow			
	Brass nozzle		IDK 90-015 C		Brass nozzle		IDK 90-015 C		Brass nozzle		IDK 90-015 C	
Temperature [°C]	10.8	± 3.6	10.0	± 0.7	19.6	± 1.1	19.8	± 0.5	18.7	± 4.3	19.8	± 4.1
Relative humidity [%]	46.1	± 1.8	45.2	± 5.0	58.2	± 3.9	57.6	± 2.3	58.9	± 4.6	54.8	± 4.9
Wind speed [m s-1]	3.2	± 1.1	3.1	± 1.1	2.8	± 1.0	2.6	± 1.2	1.9	± 0.6	2.0	± 0.6
Wind direction [°] in relation to ideal direction	2.2	± 24.8	6.7	± 24.4	13.0	± 31.7	16.3	± 23.6	5.5	± 26.4	1.85	± 23.8
Valid measurements	7		7		5		6		6		5	

Source: own compilation, JKI

Figure 36: Wind direction and wind speed during house wall application against flying insects with a knapsack sprayer on the trial area "container".

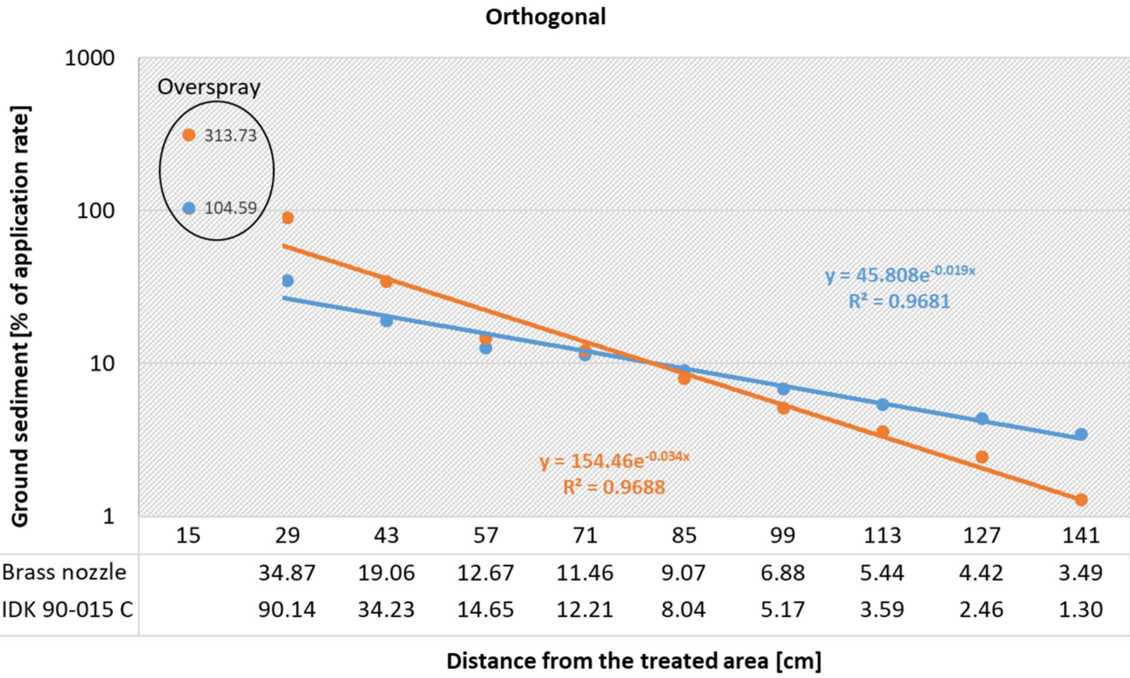


Source: own illustration, JKI

Measured drift values and recommended basic drift values

Figure 37 and Figure 38 show the 90th percentiles of the measured drift values as a percentage of the application rate during the treatment of a whole house wall with orthogonal and parallel wind direction. For both wind directions and with both nozzles, the drift values decrease with increasing distance from the house wall. In addition, it can be seen that for both wind directions, the drift values of the IDK 90-015 C nozzle are higher than the drift values of the brass nozzle at close range, but the drift values of the IDK 90-015 C nozzle decrease faster than the drift values of the brass nozzle. This effect is more pronounced with orthogonal wind direction than with parallel wind direction. Tangentially, the drift values for parallel wind direction are many times higher than the drift values for orthogonal wind direction. Thus, at a distance of 57 cm from the treated area and with parallel wind direction, a drift of 39.88% was measured with the brass nozzle and a drift of 51.82% with the IDK 90-015 C (Figure 38) and with orthogonal wind direction a drift of 12.67% was measured with the brass nozzle and a drift of 14.65% with the IDK 90-015 C (Figure 37).

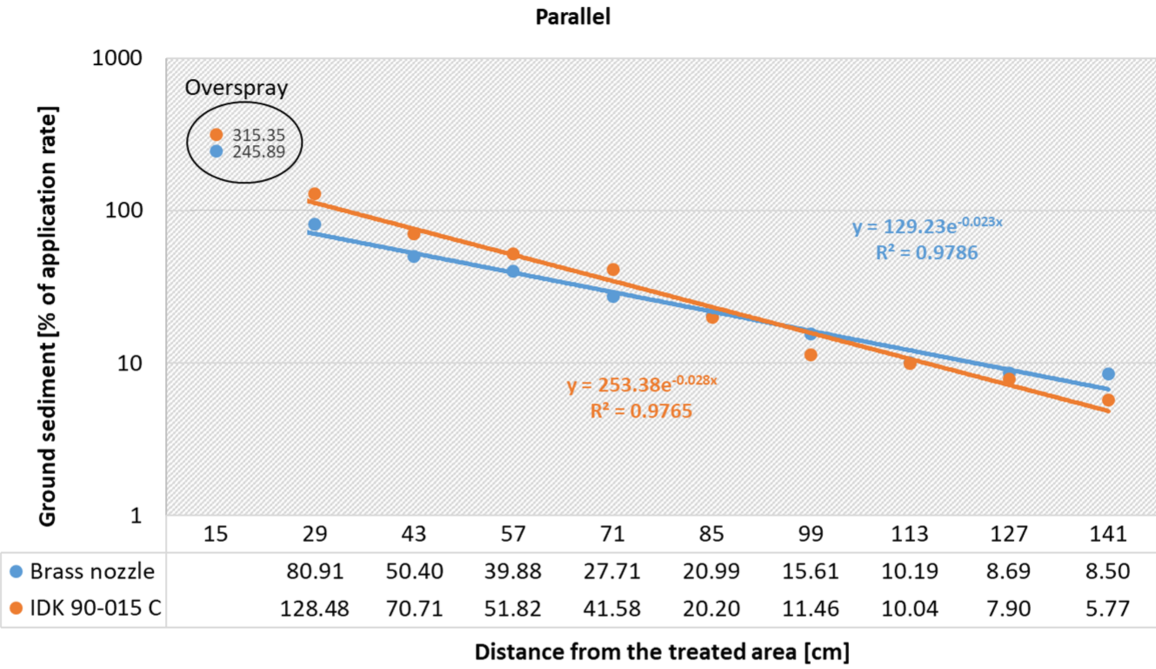
Figure 37: 90th percentile of the measured drift values in percent of the application rate during house wall application on the trial area "container" at orthogonal wind direction.



	15	29	43	57	71	85	99	113	127	141
Brass nozzle		34.87	19.06	12.67	11.46	9.07	6.88	5.44	4.42	3.49
IDK 90-015 C		90.14	34.23	14.65	12.21	8.04	5.17	3.59	2.46	1.30

Source: own illustration, JKI

Figure 38: 90th percentile of the measured drift values in percent of the application rate during house wall application on the trial area "container" at parallel wind direction.



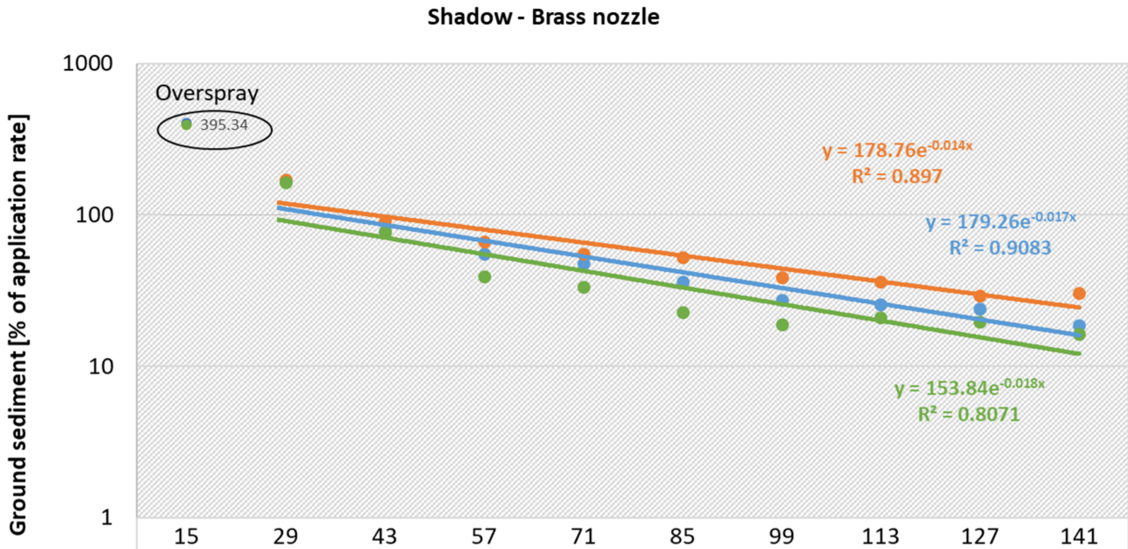
	15	29	43	57	71	85	99	113	127	141
Brass nozzle		80.91	50.40	39.88	27.71	20.99	15.61	10.19	8.69	8.50
IDK 90-015 C		128.48	70.71	51.82	41.58	20.20	11.46	10.04	7.90	5.77

Source: own illustration, JKI

When treating a house wall in the wind shadow, it was observed that the drift values decreased with increasing distance from the treated area and that the drift values of the IDK 90-015 C nozzle were higher than the drift values of the brass nozzle in the close range to the treated area, but decreased faster than the drift values of the brass nozzle.

Another effect, however, which was not observed with the other wind directions nor with the foundation application of 50 cm, is the vortex effect at the edge of the house wall. Due to the fact that the user was standing in the wind shadow of the container, turbulence occurred at the edge of the container. Figure 39 and Figure 40 show the 90th percentiles of the measured drift values as a percentage of the application rate when treating a house wall in the wind shadow, divided into entire wall, edge only and without edge. Edge only means that only the first and last row of the eight rows were considered and without edge means that the second to seventh row of the eight rows were considered. For both nozzles, the drift values when the edge is not taken into account are significantly lower than the drift values of the entire wall and the drift values when only the edge is taken into account. For the IDK 90-015 C nozzle, the drift values without the edge are two to three times lower than the drift values of the entire wall and, in some cases, four times lower than the drift values when only the edge is considered. For the brass nozzle, at a distance of 57cm from the treated surface, a drift of 66.34% was observed for the edge only, 55.29% for the entire wall, and 39.16% without the edge (Figure 39). In contrast, for the IDK 90-015 C nozzle, at a distance of 57cm from the treated surface, a drift of 103.23% was observed for the edge only, 63.34% for the entire wall, and 25.51% without the edge (Figure 40).

Figure 39: 90th percentile of the measured values of the drift in percent of the application rate during house wall application on the trial area "container" in the wind shadow with the brass nozzle.

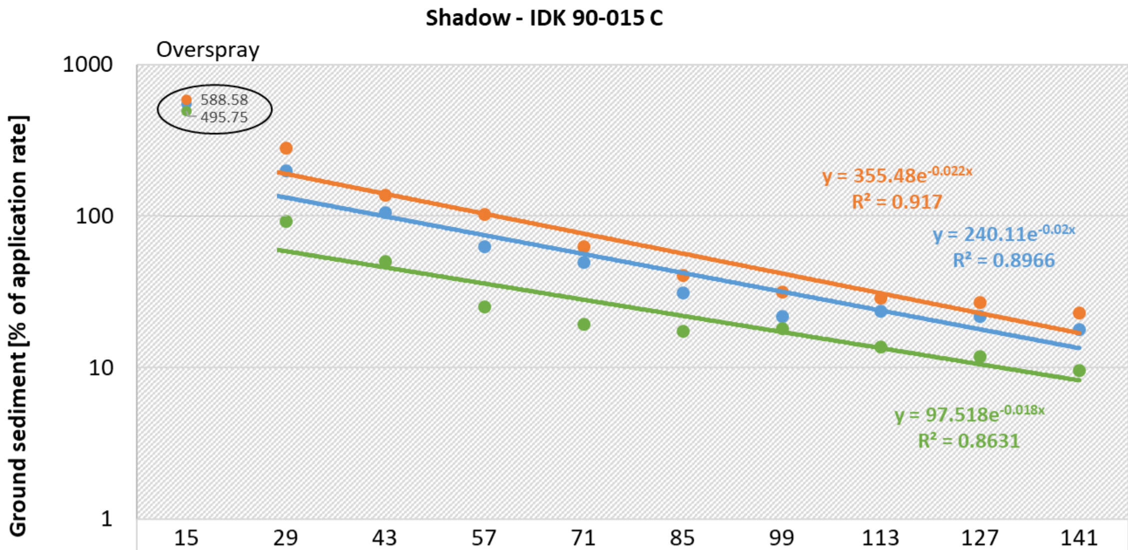


	15	29	43	57	71	85	99	113	127	141
Entire wall		167.38	77.85	55.29	47.57	36.14	27.62	25.53	23.88	18.79
Edge only		170.24	92.24	66.34	55.19	52.76	38.50	36.30	29.42	30.65
Without edge		164.23	77.33	39.19	33.66	22.66	18.90	21.06	19.72	16.28

Distance from the treated area [cm]

Source: own illustration, JKI

Figure 40: 90th percentile of the measured values of the drift in percent of the application rate during house wall application on the trial area "container" in the wind shadow with the IDK 90-015 C nozzle.



	15	29	43	57	71	85	99	113	127	141
Entire wall		200.15	106.42	63.34	49.59	31.31	21.95	23.64	22.04	17.88
Edge only		281.75	138.39	103.23	63.42	40.92	31.94	29.07	27.05	22.96
Without edge		93.44	50.79	25.51	19.56	17.42	18.22	13.82	11.85	9.69

Distance from the treated area [cm]

Source: own illustration, JKI

Table 18 shows the recommended basic drift values for a treatment of a house wall at three different wind directions based on the 90th percentile. These basic drift values were derived from the regression lines of the measured drift values. As with the foundation application of 50 cm, the lowest basic drift values were also observed for the treatment of an entire wall with orthogonal wind direction, followed by parallel wind direction and treatment in the wind shadow using an IDK 90-015 C nozzle. For the treatment in the wind shadow, the drift values without edge effect were taken into account, as the main aim of the study was to measure the drift in the wind shadow.

Table 18: Recommended basic drift values for single application derived from the measured drift values in percent of the application rate during house wall application on the trial area "container" based on 90th percentile.

Distance [cm]	Orthogonal		Parallel		Shadow - without edge	
	Brass nozzle	IDK 90-015 C	Brass nozzle	IDK 90-015 C	Brass nozzle	IDK 90-015 C
	$y = 45.808\ e^{-0.019x}$	$y = 154.46\ e^{-0.034x}$	$y = 129.23\ e^{-0.023x}$	$y = 253.38\ e^{-0.028x}$	$y = 153.84\ e^{-0.018x}$	$y = 97.518\ e^{-0.018x}$
29	26.40	57.62	66.33	112.49	91.28	57.86
43	20.24	35.80	48.07	76.01	70.95	44.97
57	15.51	22.24	34.83	51.36	55.14	34.95
71	11.89	13.82	25.24	34.71	42.86	27.17
85	9.11	8.58	18.29	23.45	33.31	21.12
99	6.98	5.33	13.26	15.85	25.89	16.41
113	5.35	3.31	9.61	10.71	20.12	12.76
127	4.10	2.06	6.96	7.23	15.64	9.91
141	3.14	1.28	5.05	4.89	12.16	7.71

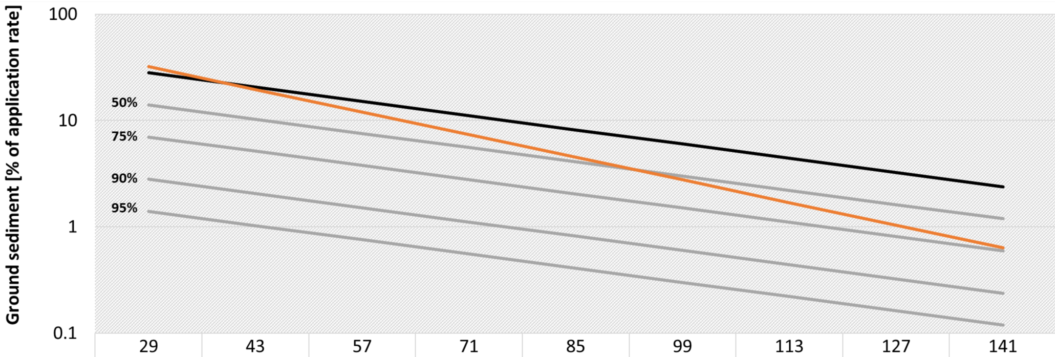
Source: own compilation, JKI

Drift mitigation measures

In contrast to the treatment of the foundation of 50 cm, a significant effect of the nozzles used can be observed when treating a house wall. Figure 41 shows the drift mitigation classes according to JKI guideline 2.2-1 over all three wind directions based on the adjusted medians of the brass nozzle and, in comparison, the adjusted medians of the IDK 90-015 C nozzle. A general classification of the IDK 90-015 C nozzle is not possible, as it does not fall below any of the drift mitigation classes over the entire measuring area. However, a drift mitigation of 50% is possible from a distance of 99 cm from the treated area.

Just as with the foundation application, a significant effect of the wind direction can also be seen when treating the entire wall. With orthogonal wind direction, significantly lower drift values were measured than with parallel wind direction or treatment of the house wall in the wind shadow (Figure 42).

Figure 41: Median value and drift mitigation classes based on drift values on the trial area "container" for house wall application.



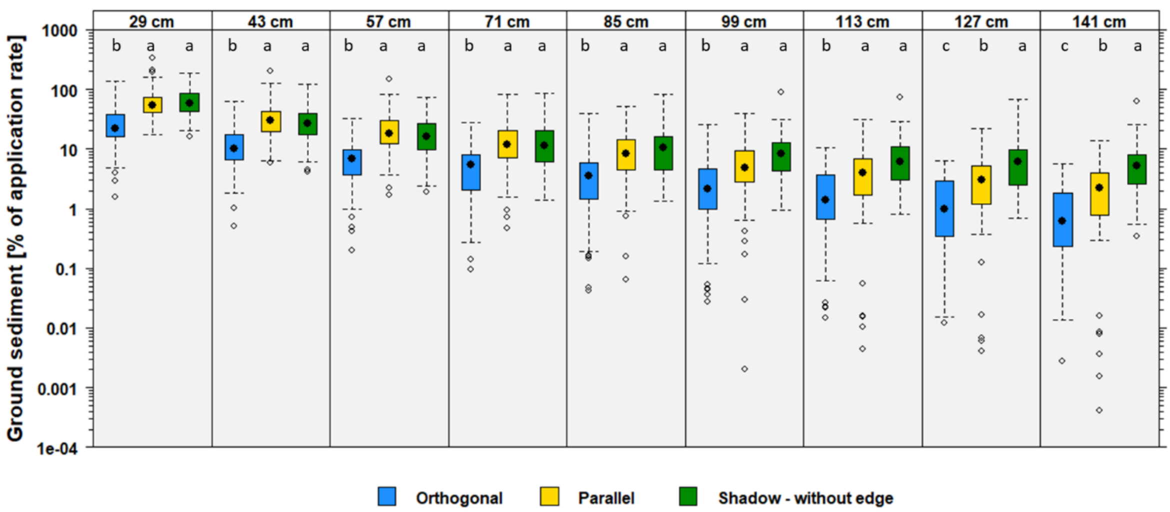
	29	43	57	71	85	99	113	127	141
Basis value, Brass nozzle	28.03	20.60	15.14	11.13	8.18	6.01	4.42	3.25	2.39
50% drift mitigation	14.02	10.30	7.57	5.56	4.09	3.00	2.21	1.62	1.19
75% drift mitigation	7.01	5.15	3.78	2.78	2.04	1.50	1.10	0.81	0.60
90% drift mitigation	2.80	2.06	1.51	1.11	0.82	0.60	0.44	0.32	0.24
95% drift mitigation	1.40	1.03	0.76	0.56	0.41	0.30	0.22	0.16	0.12
IDK 90-015 C	32.02	19.62	12.02	7.36	4.51	2.76	1.69	1.04	0.64

Distance from the treated area [cm]

* Shadow without edge

Source: own illustration, JKI

Figure 42: Measured drift values in percent of the application rate during house wall application on the trial area "container" as a function of the wind direction (Median.Test, α = 0.05).



Source: own illustration, JKI

3.5 Run-off values on the trial area "container"

An overview of the application rate is shown in Table 10. An application rate of 100 mL m^{-2} was aimed for in the full application rate variant and an application rate of 50 mL m^{-2} in the half application rate variant. A change in application rates was achieved between the variants by different walking times. In the full application rate variant, the real application rate was 112 mL m^{-2} and in the half application rate variant, the real application rate was 53 mL m^{-2} (Table 19). The differences between the nozzles used do not influence the result.

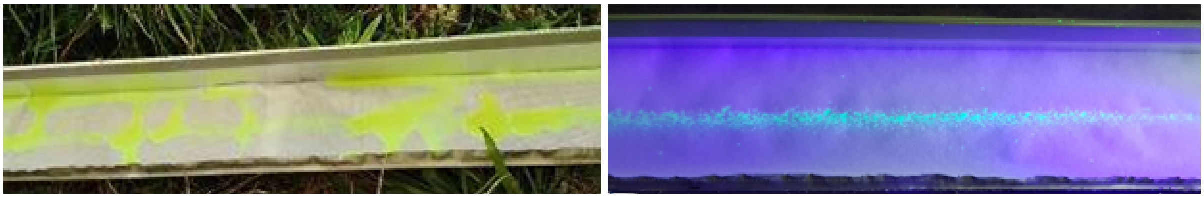
Table 19: Overview of the real sprayed quantity [mL] and application rate [mL m^{-2}] of the two variants full and half application rate.

Nozzle	Full application rate		Half application rate	
	Sprayed quantity [mL]	Application rate [mL m^{-2}]	Sprayed quantity [mL]	Application rate [mL m^{-2}]
Brass nozzle	245	108.9	110	48.9
	245	108.9	110	48.9
	245	108.9	135	60.0
	250	111.1	110	48.9
	245	108.9	110	48.9
			135	60.0
IDK 90-015 C	255	113.3	115	51.1
	275	122.2	120	53.3
	255	113.3	125	55.6
	250	111.1	115	51.1
	255	113.3	120	53.3
			125	55.6
Mean	**252** ± 9.2	**112** ± 4.1	**119.2** ± 9.3	**53** ± 4.1

Source: own compilation, JKI

The different application rates resulted in different runoff, which was also visually apparent directly after application. With the full application rate variant (112 mL m^{-2}), the fleece in the profile could not collect all the liquid (Figure 43, left). Therefore, the liquid had to be tipped into the wide-mouth glasses and then the fleece was carefully placed into the wide-mouth glasses as well. In contrast, at half the application rate (53 mL m^{-2}), the runoff was only visible with the help of a black light lamp, regardless of the nozzle used (Figure 43, right).

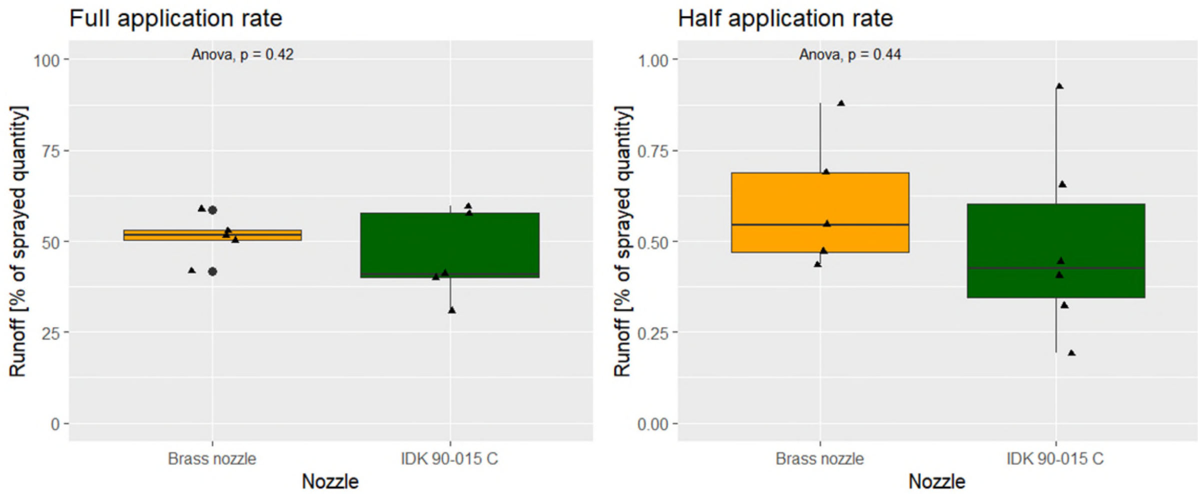
Figure 43: Inside of the profile after application of the full application rate (left) and the half application rate (right).



Source: JKI

The laboratory analysis of the fleece confirms this visual impression. Figure 44 shows the runoff values with a knapsack sprayer with the brass nozzle and the nozzle IDK 90-015 C at full and half application rate. Regardless of the nozzles, runoff up to 50% of the sprayed quantity was observed at full application rate of 112 mL m^{-2}. In comparison, at half application rate of 53 mL m^{-2}, runoff of less than 1% of the sprayed quantity was observed. This means that reducing the application rate by 50% results in the spread liquid remaining on the wall and not entering the soil. Increasing the application rate only increases the runoff, but not the part that remains on the wall.

Figure 44: Measured runoff values in percent of the sprayed quantity on the trial area "container".



Source: own illustration, JKI

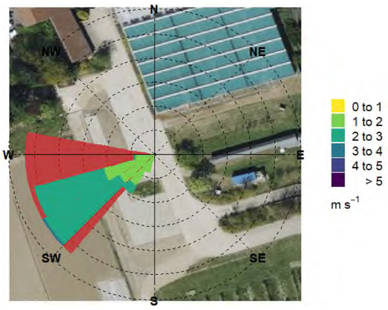
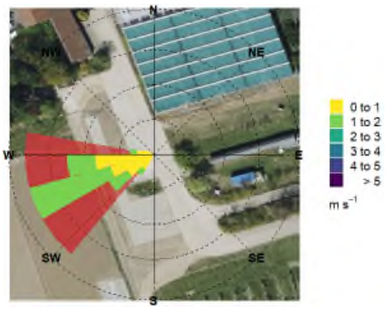
3.6 Drift values on the trial area "paved path"

Meteorological conditions during the application

During the measurement of the drift during the treatment of a paved path for algae removal with a knapsack sprayer with two different nozzles, the mean air temperature was between 17.8 °C and 20 °C, the mean relative humidity was between 61.6% and 68.4% and the mean wind speed was between 1.1 m s^{-1} and 2.2 m s^{-1}. The mean deviation from the nominal wind direction was between -10° and 0.9°. The wind rose shows the wind direction and the wind speed during the treatment of the path.

Table 20: Mean values of meteorological conditions during path application with a knapsack sprayer on the trial area "paved path".

Parameters	Brass nozzle		IDK 90-015 C	
Temperature [°C]	17.8	± 0.1	20	± 0.2
Relative humidity [%]	68.4	± 0.2	61.6	± 1.3
Wind speed [m s-1]	2.1	± 0.4	1.1	± 0.3
Wind direction [°] in relation to ideal direction	- 10	± 10.5	0.9	± 17.2

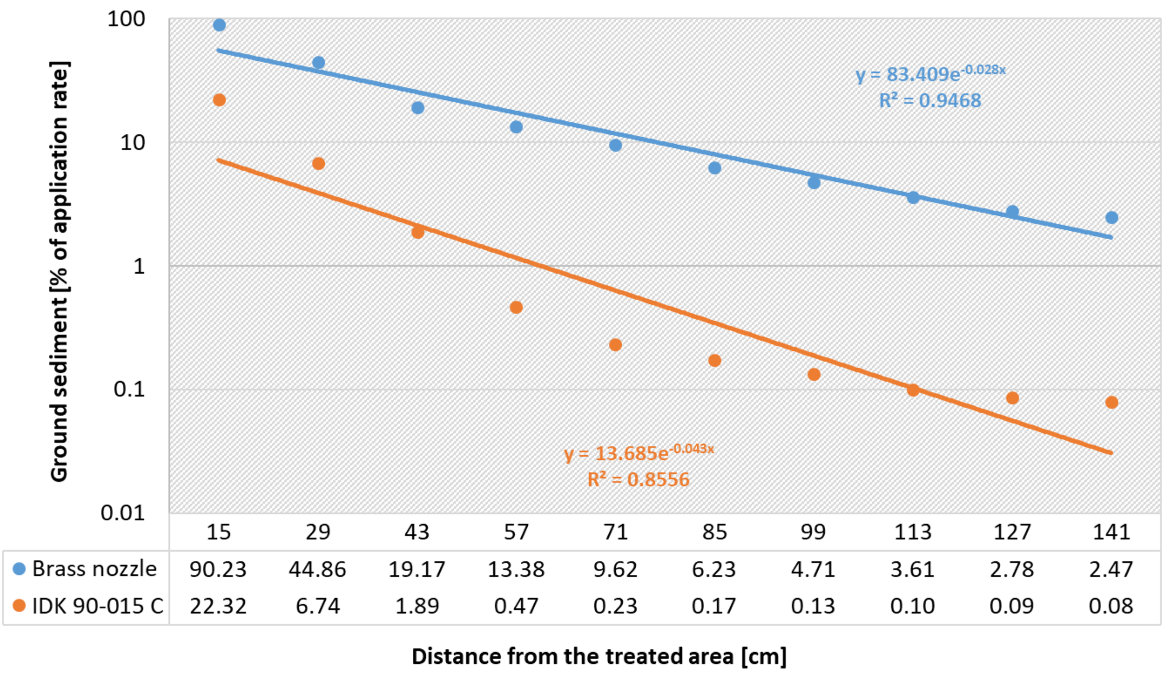
Parameters	Brass nozzle	IDK 90-015 C
Wind rose		

Source: own compilation, JKI

Measured drift values and recommended basic drift values

Figure 45 shows the 90th percentile of the measured drift values during the treatment of a paved path with a knapsack sprayer with brass nozzle and with IDK 90-015 C nozzle. For both nozzles, drift decreases with increasing distance from the treated area. However, it can be seen that the drift of the brass nozzle is much higher than the drift of the IDK 90-015 C nozzle. Thus, in the first collector, at a distance of 15 cm from the treated area, a drift of 90.23% was found with the brass nozzle and a drift of 22.32% with the IDK 90-015 C nozzle. At a distance of 99 cm from the treated area, the drift with the brass nozzle was still 4.71% and with the IDK 90-015 C nozzle only 0.13%. The recommended basic drift values derived from the regression line are shown in Table 21.

Figure 45: 90th percentile of the measured drift values in percent of the application rate during application on the trial area "paved path".



Source: own illustration, JKI

Table 21: Recommended basic drift values for single application derived from the measured drift values in percent of the application rate during application on the trial area “paved path” based on 90th percentile.

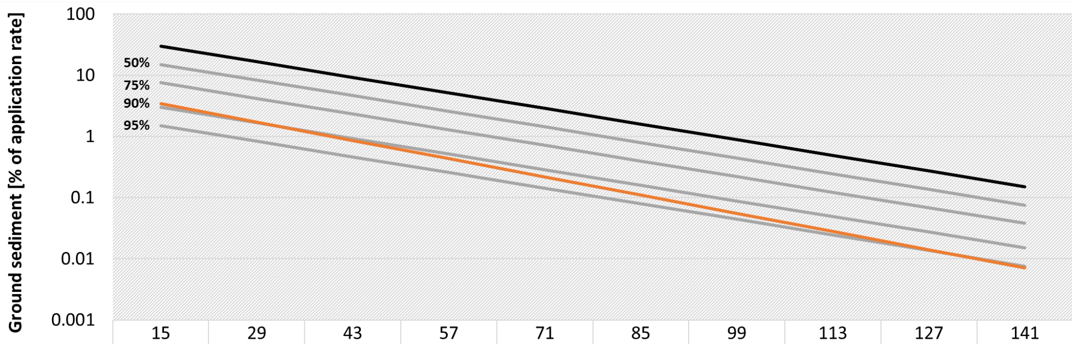
Distance [cm]	Brass nozzle $y = 83.409\ e^{-0.028x}$	IDK 90-015 C $y = 13.685\ e^{-0.043x}$
15	54.80	7.18
29	37.03	3.93
43	25.02	2.15
57	16.91	1.18
71	11.42	0.65
85	7.72	0.35
99	5.22	0.19
113	3.52	0.11
127	2.38	0.058
141	1.61	0.032

Source: own compilation, JKI

Drift mitigation measures

A significant drift mitigation when treating a paved path can be achieved with the choice of nozzle. Figure 46 shows that a drift mitigation of up to 75% over the entire measuring area is possible if an IDK 90-015 C nozzle is used instead of a brass nozzle. A drift mitigation of 90% can be achieved at a distance of 43 cm from the treated area.

Figure 46: Median value and drift mitigation classes based on drift values on the trial area "paved path".



	15	29	43	57	71	85	99	113	127	141
Basis value, Brass nozzle	30.11	16.73	9.29	5.16	2.87	1.59	0.88	0.49	0.27	0.15
50% drift mitigation	15.06	8.36	4.64	2.58	1.43	0.80	0.44	0.25	0.14	0.076
75% drift mitigation	7.53	4.18	2.32	1.29	0.72	0.40	0.22	0.12	0.068	0.038
90% drift mitigation	3.01	1.67	0.93	0.52	0.29	0.16	0.088	0.049	0.027	0.015
95% drift mitigation	1.51	0.84	0.46	0.26	0.14	0.080	0.044	0.025	0.014	0.0076
IDK 90-015 C	3.40	1.71	0.86	0.43	0.22	0.11	0.056	0.028	0.014	0.0071

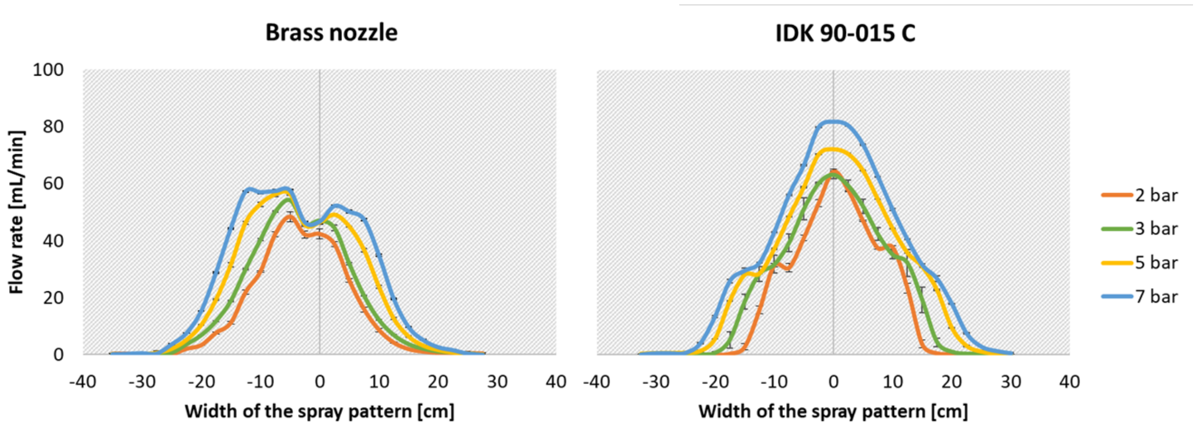
Distance from the treated area [cm]

Source: own illustration, JKI

3.7 Distribution accuracy of nozzles

Figure 47 shows the distribution accuracy of the brass nozzle and the IDK 90-015 C at a working height of 20 cm and different working pressures. Both nozzles have a very similar spray angle as the width of the spray pattern is very similar. The differences are in the shape of the spray pattern. Characteristically, the spray pattern of the IDK 90-015 C nozzle is pointed and the brass nozzle shows a wide plateau with a small depression in the middle of the plateau. Increasing the working pressure from 2.0 bar to 3.0, 5.0 and 7.0 bar causes the spray pattern to become wider and the flow rate to increase for both. In addition, the brass nozzle runs out softer at the edge than the IDK 90-015 C nozzle and this effect is intensified at higher pressure.

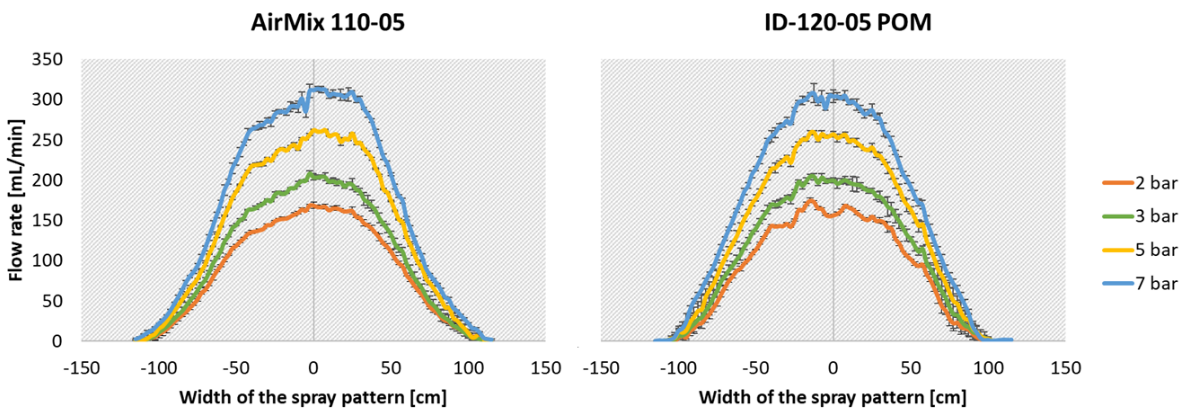
Figure 47: Distribution accuracy in the single nozzle test bench at a working height of 20 cm.



Source: own illustration, JKI

The distribution accuracy of the AirMix 110-05 and ID-120-05 POM in a combination of 5 nozzles at a working height of 50 cm, a distance to each other of 25 cm and different working pressures is shown in Figure 48. The nozzles are wide angle nozzles and show a very similar spray pattern with a very similar flow rate in combination with 5 nozzles. Increasing the working pressure from 2.0 bar to 3.0, 5.0 and 7.0 bar only leads to an increase in the flow rate but does not change the spray pattern significantly.

Figure 48: Distribution accuracy in the single nozzle test bench in a configuration of 5 nozzles at a working height of 50 cm.

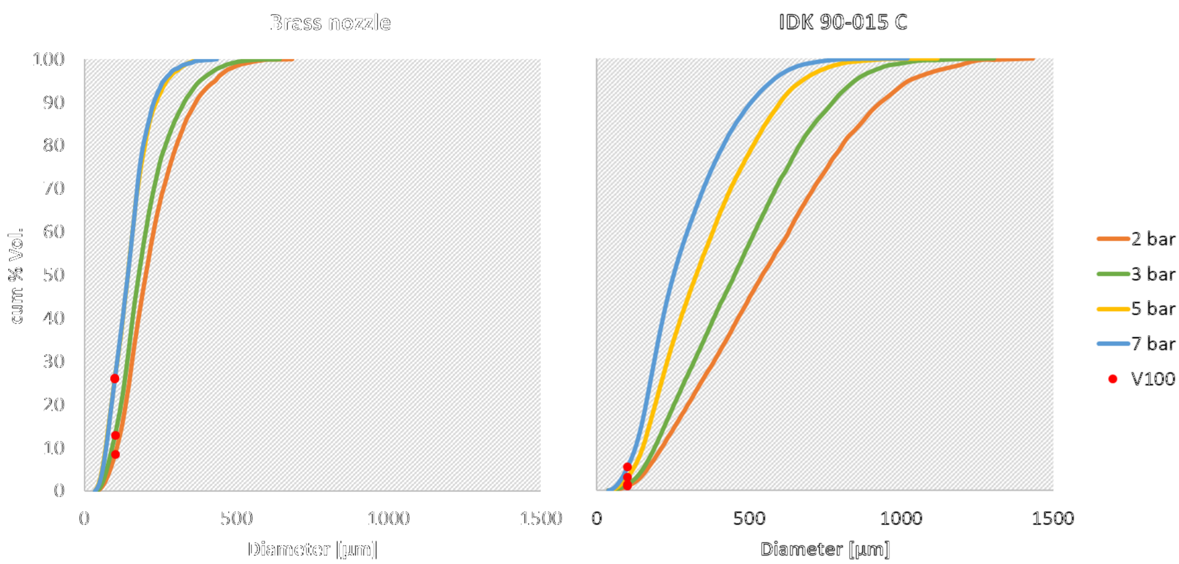


Source: own illustration, JKI

3.8 Droplet size distribution of nozzles

Figure 49 shows the cumulative drop size distribution of the brass nozzle and the IDK 90-015 C at the working pressures of 2.0, 3.0, 5.0 and 7.0 bar. For both nozzles it can be seen that the curves rise more steeply with increasing working pressure. With increasing pressure, the proportion of fine drops increases and the proportion of large drops decreases. There is no difference in the distribution of droplet size between the working pressures of 5.0 and 7.0 bar for the brass nozzle. A comparison of the nozzles within one working pressure clearly shows that the curves of the brass nozzle are much steeper than the curves of the IDK 90-015 C. The brass nozzle thus has a higher proportion of fine droplets and a lower proportion of droplets than the IDK 90-015 C. This is also reflected in the volumetric mean diameter (VMD) data. This value is used to classify the nozzles into a droplet size class. The VMD of the brass nozzle is 208.2 µm at 2.0 bar, 184.5 µm at 3.0 bar, 146.6 µm at 5.0 bar and 146.8 µm at 7.0 bar. According ISO (2018), this corresponds to a drop size classification of "Fine" for 2.0 bar and 3.0 bar and of "Very Fine" for 5.0 bar and 7.0 bar. The VMD of the IDK 90-015 C is 561.9 µm at 2.0 bar, 467.4 µm at 3.0 bar, 336.8 µm at 5.0 bar and 260.1 µm at 7.0 bar. According ISO (2018), this corresponds to a drop size classification of "Extremely Coarse" for 2.0 bar, of “Very Coarse” for 3.0 bar, of “Coarse” for 5.0 bar and of "Medium" for 7.0 bar. Another classification feature is the V_{100} value. V_{100} indicates the percentage of droplets that have a diameter smaller than 100 µm and are therefore potentially drift-prone. For the brass nozzle at 2.0 bar it is 8.51%, at 3.0 bar it is 12.9%, at 5.0 bar it is 26.2% and at 7.0 bar it is 26.0%. With the IDK 90-015 C, the V_{100} values are clearly below the values of the brass nozzle and thus show a significantly reduced drift susceptibility. With the IDK 90-015 C it is 0.99% at 2.0 bar, 1.43% at 3.0 bar, 3.12% at 5.0 bar and 5.4% at 7.0 bar.

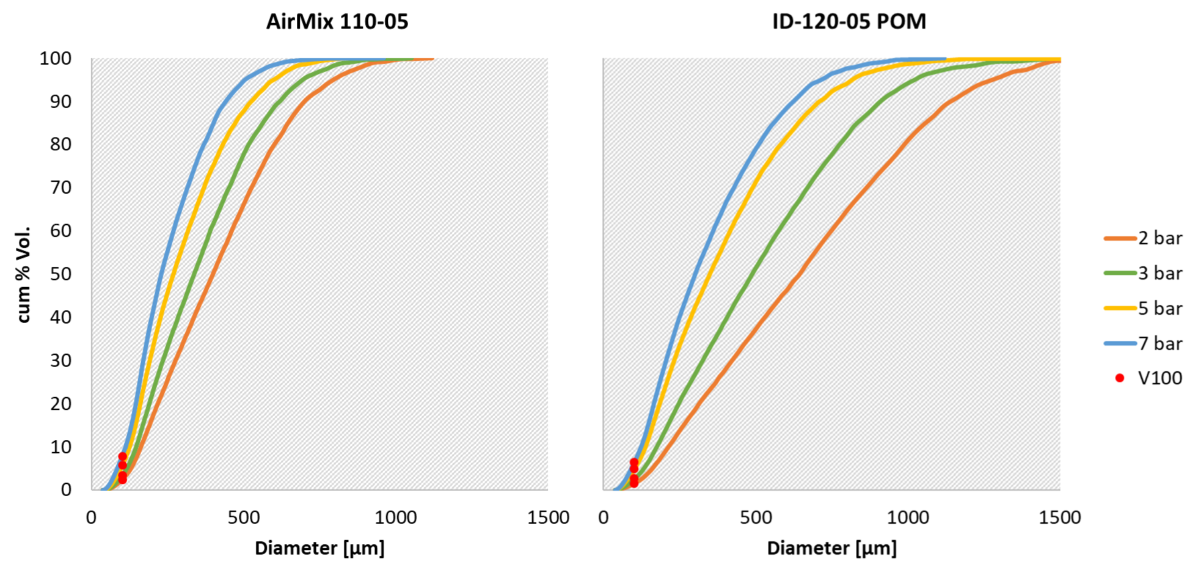
Figure 49: Cumulative drop size distribution of the brass nozzles and IDK 90-015 C with indication of the value V_{100} for the drop fraction smaller than 100 µm (red dot) depending on the working pressure.



Source: own illustration, JKI

Figure 50 shows the cumulative drop size distribution of the AirMix 110-05 and the ID-120-05 POM at the working pressures of 2.0, 3.0, 5.0 and 7.0 bar. The working pressure also influences the drop size distribution for these two nozzles. With increasing working pressure, the curves increase more steeply and the proportion of fine droplets increases and the proportion of large droplets decreases. The difference between the curves at 2.0 and 7.0 bar is greater with the ID-120-05 POM than with the AirMix 110-05. However, the curves are generally steeper with the AirMix 110-05 than with the ID-120-05 POM. This indicates a larger proportion of fine droplets and a smaller proportion of coarse droplets with the AirMix 110-05 than with the ID-120-05 POM. This also becomes clear when comparing the values of the VMD. With the AirMix 110-05, the VMD at 2.0 bar is 411.7 µm, at 3.0 bar 348.2 µm, at 5.0 bar 278.3 µm and at 7.0 bar 236.6 µm. In the drop size classification according ISO (2018), this means that this nozzle is classified as "Very Coarse" at 2.0 and 3.0 bar and as "Medium" at 5.0 and 7.0 bar. The ID-120-05 POM shows VMD values of 664.2 µm at 2.0 bar, 503 µm at 3.0 bar, 359.9 µm at 5.0 bar and 310.1 µm at 7.0 bar. And is therefore classified according ISO (2018) as "Ultra Coarse" at 2.0 bar, as "Extremely Coarse" at 3.0 bar, as "Very Coarse" at 5.0 bar and as "Coarse" at 7.0 bar. In contrast, the V_{100} values of both nozzles are not so clearly different from one another. With the AirMix 110-05, the V_{100} value at 2.0 bar is 2.4%, at 3.0 bar 3.32%, at 5.0 bar 5.67% and at 7.0 bar 7.81%. With the ID-120-05 POM, the V_{100} value is 1.54% at 2.0 bar, 2.58% at 3.0 bar, 4.84% at 5.0 bar and 6.43% at 7.0 bar.

Figure 50: Cumulative drop size distribution of the AirMix 110-05 and ID-120-05 POM with indication of the value V_{100} for the drop fraction smaller than 100 µm (red dot) depending on the working pressure.

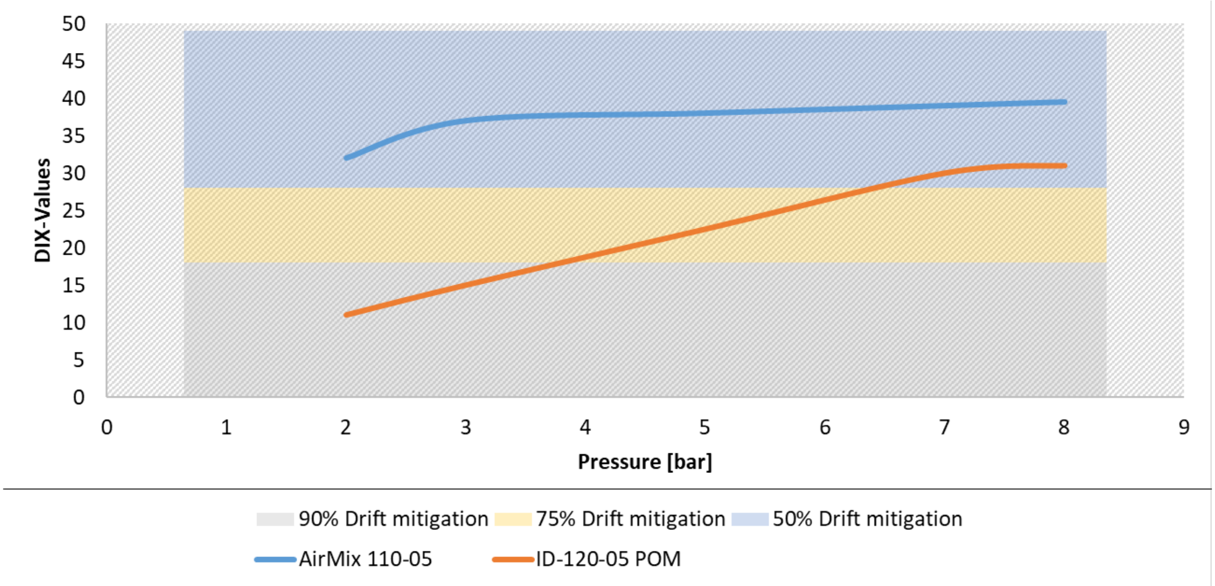


Source: own illustration, JKI

3.9 Drift potential index of nozzles

For the AirMix 110-05 and ID-120-05 POM nozzles, Figure 51 shows the calculated DIX values and the drift potential derived from them. With increasing working pressure, the DIX value increases and the drift reduction decreases. Based on arable test conditions in the wind tunnel, the DIX values of the AirMix 110-05 are 32, 37, 38 and 39 at a working pressure of 2, 3, 5 and 7.0 bar and thus above a DIX value of 28. This means that the AirMix 110-05 can be classified with a drift mitigation of 50% over the entire measuring range. The DIX values of the ID-120-05 POM are 11, 15, 22.5 and 30 at a working pressure of 2.0, 3.0, 5.0 and 7.0 bar. If this nozzle is used at 2.0 and 3.0 bar, there is a drift mitigation of 90%. At 5.0 bar the drift mitigation is 75% and at 7.0 bar the drift mitigation is 50%.

Figure 51: DIX values and drift mitigation potential after wind tunnel tests of the nozzles AirMix 110-05 and ID-120-05 POM.



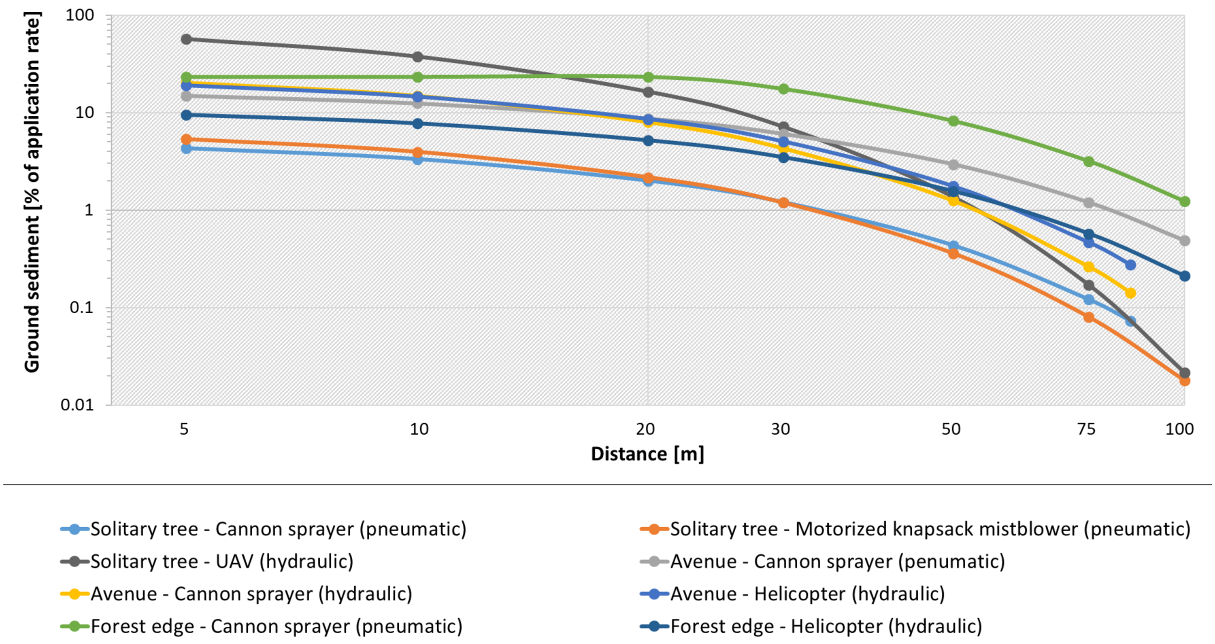
Source: own illustration, JKI

4 Discussion

4.1 Transferability of basic drift values from plant protection

Whether the basic drift values from plant protection can be adopted for the biocide sector was already answered partly in the report of the previous project, but since this is the core question of both projects, this topic is taken up again. An overview of the recommended basic drift values derived from the drift trials described above is shown in Figure 52. For the applications with hydraulic atomisation, the values given refer to the trials with the AirMix 110-05 nozzle as the AirMix 110-05 nozzle is a standard nozzle widely used in Europe. The ID-120-05 POM nozzle is a drift mitigation nozzle of the latest generation and also showed the highest drift mitigation potential in these trials. Therefore, nozzles of this category are recommended as drift mitigation measures and are not suitable for the definition of basic drift values, which represent a worst-case scenario.

Figure 52: Recommended basic drift values [%] derived from the measured drift values for different application areas and devices, based on the 90th percentile



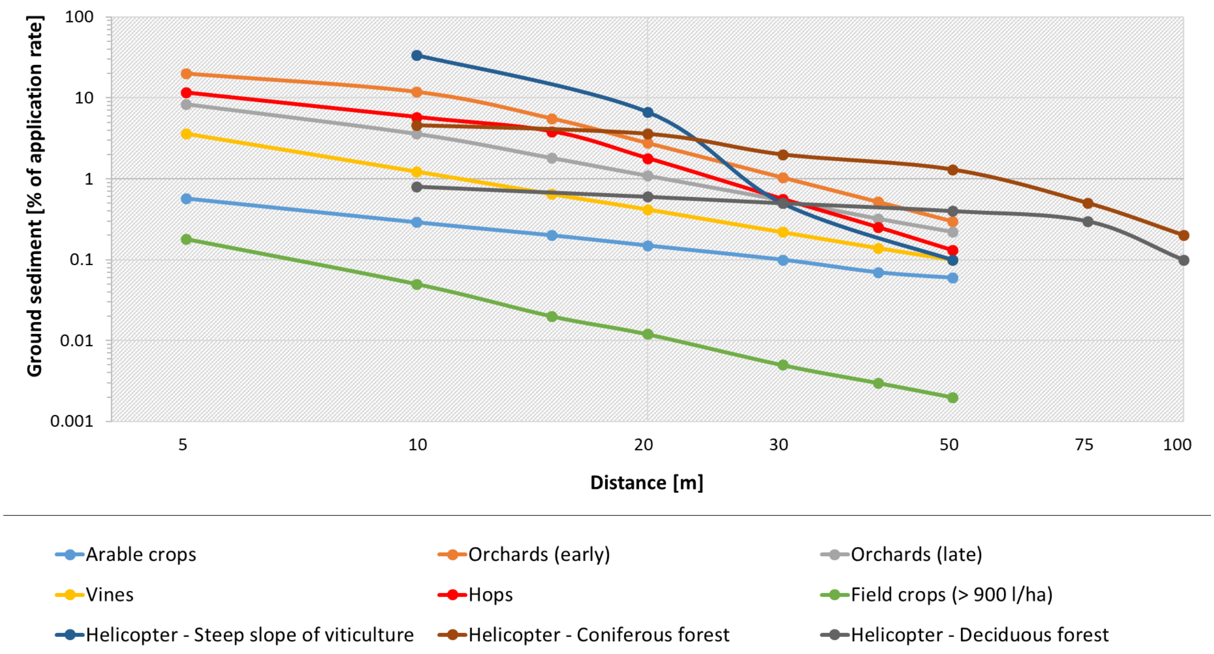
Basic drift values for the trial area "solitary tree" are based on the maximum values.
Source: own illustration, JKI

Figure 53 shows the basic drift values from plant protection published by the JKI (JKI 2022b). Compared to the recommended basic drift values for biocides (Figure 52), the 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 could be the technique, the direction of spraying and the distance between nozzles and treated area. While in the treatment of field crops the distance between nozzles and crops is 30 to 50 cm, depending on the technique, the distance between a cannon sprayer or a helicopter and a tree crown is several meters (Figure 11). The influence of external factors on spray drift is therefore much larger. Similarly, a field sprayer sprays vertically from top to bottom and a cannon sprayer sprays from bottom in the treetop.

Another observation is that the basic drift values for helicopter use with plant protection products in the deciduous forest are significantly lower than for helicopter use at the edge of the deciduous forest with biocidal products. This is due to the fact that no plant protection measure is allowed to take place at the edge of the forest and must be omitted (BMJ 2012). Thus, the distance between the treated area and the zero point (crown edge) is larger in plant protection comparted to biocide treatment.

Due to the size of the plants, it was proposed earlier to adopt the basic drift values of the hops treatment for oak processionary moth control. However, as these drift experiments show, it is not only the height of 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.

Figure 53: 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 2022b)



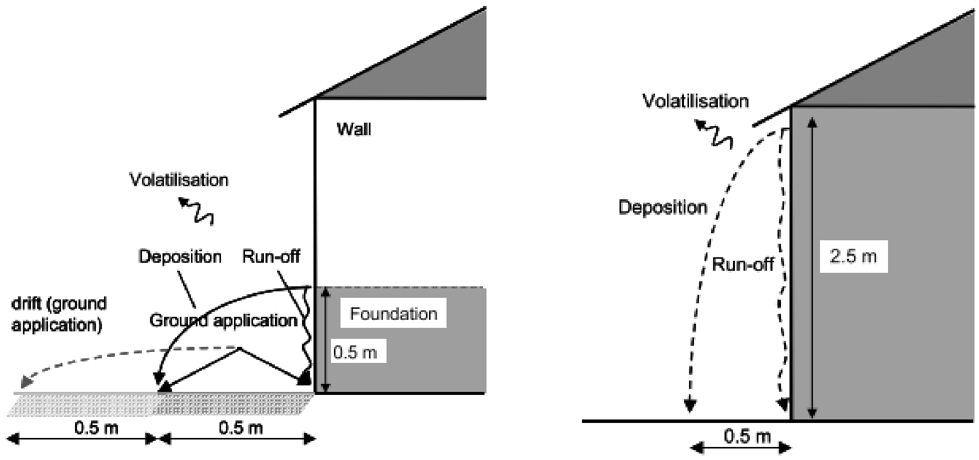
Source: own illustration, JKI

The drift trials carried out not only serve to derive basic drift values for the risk assessment in the authorisation of plant protection products, but also serve as the basis for deriving drift mitigation classes. These drift mitigation classes are used to add devices to the JKI's list of loss-reducing devices for plant protection. Adopting the basic drift values from plant protection for the biocide sector would mean that the drift mitigation classes are adopted as well. There is still no approval procedure for devices for biocide application, but if there was one combined with the testing of devices, there would be a risk that the devices for biocide application would not receive any drift mitigation classes if they were compared to the values for devices for plant protection products. It is therefore all the more important that the techniques and application areas for biocide applications are known and that specific basic drift values are derived that can be used for a separate assessment of biocides equipment, independent from the application devices of plant protection products.

4.2 Transferability of basic drift values from default values of the Emission Scenario Document

In 2008, the Organisation for Economic Co-operation and Development (OECD) published an Emission Scenario Document (ESD) for insecticides, acaricides and other arthropod control products for household and professional use (OECD 2008). This document describes application areas and gives default values for the emitted fraction. Figure 54 shows the emission pathways when treating a foundation and ground against crawling insects and a house wall against flying insects. Table 22 shows the associated default values. Fractions emitted into the air during application are not considered in either scenario. Fractions that are deposited on the ground during spray application are evaluated with 10% for both scenarios. Fractions that reach the ground through run-off during spray application are evaluated at 20% for both scenarios. Fractions that reach the ground directly during spray application are evaluated with 99% for treatment against crawling insects. Fractions that reach the adjacent untreated zone during spray application are evaluated with 0.42% in the treatment against crawling insects. And finally, fractions that reach the ground due to rain are evaluated with 50% for both scenarios.

Figure 54: Emission pathways during spray application on grounds and foundations against crawling insects (left) and on walls against flying insects (right).



Source: OECD (2008)

Table 22: Default values in percent for emission factors during outdoor spray perimeter treatment against flying and crawling insects.

Variable/parameter	Symbol	Default value crawling insects	Default value flying insects
Fraction emitted to air during outdoor spray application	$F_{spray,air}$	0.00	0.00
Fraction emitted to soil during spray application due to deposition	$F_{spray,deposition}$	10.0	10.0
Fraction emitted to soil during spray application due to run-off	$F_{spray,run-off}$	20.0	20.0
Fraction directly emitted to soil during spray application	$F_{spray,soil}$	99.0	

Variable/parameter	Symbol	Default value crawling insects	Default value flying insects
Fraction emitted to soil during spray application in the adjacent untreated zone	$F_{spray,untreated\ soil}$	0.42	
Fraction emitted to soil due to foundation wash-off by rainfall	$F_{spray,wash\text{-}off}$	50.0	50.0

Source: OECD (2008)

In the present project, drift was measured when treating a chemical barrier of 50 cm against crawling insects and when treating a house wall against flying insects up to a distance of 183 cm from the treated area. At a distance of 57 cm from the treated area, a drift value of 0.68% with the brass nozzle and 0.34% with the IDK 90-015 C nozzle in orthogonal wind direction, of 5.90% with the brass nozzle and 4.78% with the IDK 90-015 C nozzle in parallel wind direction and of 7.34% with the brass nozzle and 5.46% with the IDK 90-015 C nozzle in wind shadow applications was measured for a foundation application of 50 cm (Table 16). According to the described default values of the OECD in the ESD, a value of 10% should be considered for the fractions reaching the ground during the spray application. With both nozzles and the three wind directions, this default value was met.

However, evaluating the drift of a sprayer or nozzle based on a drift value for only one distance to the treated area can lead to misinterpretations. This becomes clear when treating an entire house wall to control flying insects. With both, an orthogonal and a parallel wind direction, a higher drift was measured with the IDK 90-015 C nozzle than with the brass nozzle at a distance of 57 cm from the treated area. However, it should be noted that the drift decreased faster with the IDK 90-015 C nozzle than with the brass nozzle, due the different droplet size. Thus, although the drift close to the treated area is higher with the IDK 90-015 C nozzle, the total contaminated area is smaller with the IDK 90-015 C nozzle than with the brass nozzle. This is not made clear by considering only one distance, and a risk assessment based on one distance is also not appropriate. The JKI guideline 7-1.5 for measuring direct drift when applying liquid plant protection products in the field states that at least 5 distances from the treated area are necessary to ensure the comparability of the tests (JKI 2013b). This procedure is also recommended for the evaluation of drift from house walls or masonry in order to better assess the risk.

Another area of study was the run-off from the application of a chemical barrier. In the ESD, a fraction of 20% is stated to reach the ground through run-off during spraying. In the present study, a run-off of 0.5% and 50% of the sprayed quantity was observed depending on the application rate.

4.3 Possibilities for drift mitigation

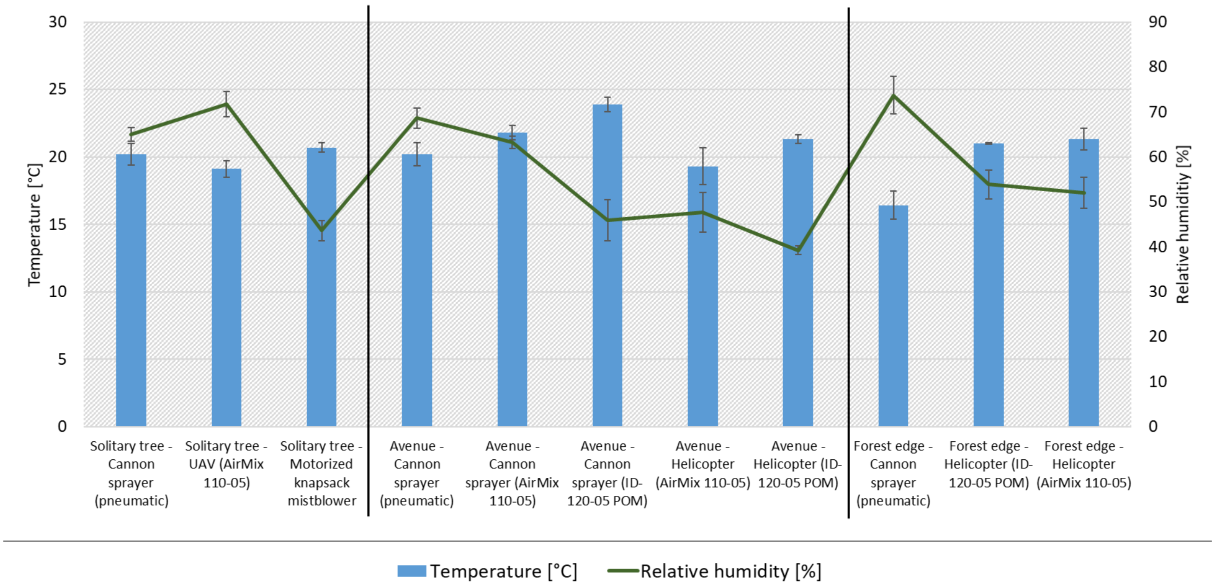
4.3.1 Influence of weather conditions on drift

Drift can be influenced by weather conditions, especially wind speed, temperature, relative humidity and atmospheric stability (Miller & Bellinder 2001; Nuyttens et al. 2006a; Franke et al. 2010; Arvidsson et al. 2011). Field spray measurements and subsequent modelling have shown that conditions with different air temperatures and relative humidity at constant wind speeds influence the drift potential more than conditions with different wind speeds at constant air temperatures and relative humidity. According to this, an increase in air temperature from 13.4 °C to 21.7 °C and a decrease in relative humidity from 90% to 40% lead to an increase in drift potential from 4% to 10% at 1 m from the treated area (Nuyttens et al. 2006a). Nuyttens et al. (2006a) observed the greatest impact due to decreasing relative humidity up to 5 m from the treated area. At a distance of 5 m from the treated area, a decrease in relative humidity from 60% to 40% increased the drift potential by less than 1%. This is because the droplet diameter gradually decreases as the water contained in the droplet evaporates and smaller droplets have a higher drift potential than larger droplets (Holterman et al. 1997; Miller & Bellinder 2001; Miller 2003; Hilz & Vermeer 2013).

In the present study, the influence of decreasing relative humidity on the amount of drift of the spray could not be observed. The trials at the trial area “avenue” with a hydraulic cannon sprayer and two different nozzles were carried out on the same day. The measurements with the AirMix 110-05 nozzle were made in the morning and the measurement with ID-120-05 POM in the afternoon. During the day, the weather conditions were constant except for the relative humidity. The relative humidity decreased from 63.2% to 45.9% during the day (Figure 55). According to Nuyttens et al. (2006a), droplet size was probably smaller and drift potential higher in the afternoon due to lower humidity. In this study, drift values were consistently lower when using the ID-120-05 POM nozzles in the afternoon at lower relative humidity than when using the AirMix 110-05 nozzles in the morning at higher relative humidity. Similar situations were also observed at the trial areas "solitary tree" and "forest edge". Despite lower relative humidity in the trials with a motorised knapsack mistblower at the trial area "solitary tree" and a helicopter at the trial area "forest edge", lower drift values were observed than with the comparative techniques and lower relative humidity. Even taking wind speed into account, lower drift values were observed with a hydraulic cannon sprayer and higher wind speeds than with a pneumatic cannon sprayer and lower wind speeds at the trial area "avenue" (Figure 56).

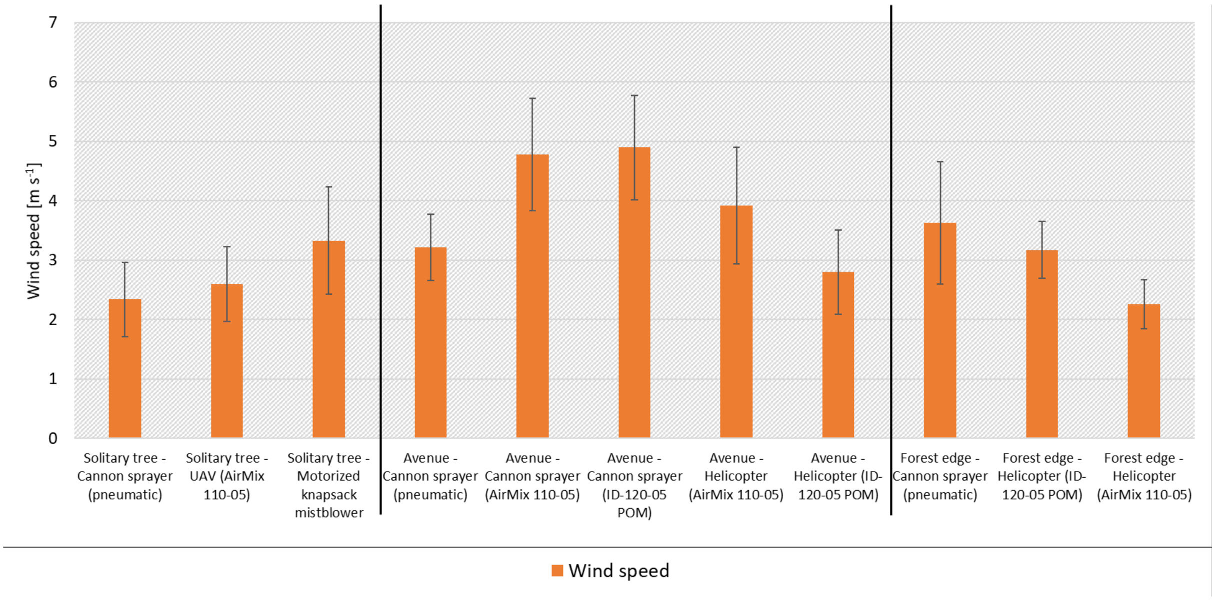
From all this, it can be concluded that the influence of the nozzles and technology on drift is greater than the influence of weather conditions. However, it should be taken into account that the weather conditions were within the guideline values set by the JKI and that applications outside the JKI guideline 7-1.5 (JKI 2013b) were not considered.

Figure 55: Overview of air temperature and relative humidity during the trials to measure drift in OPM control.



Source: own illustration, JKI

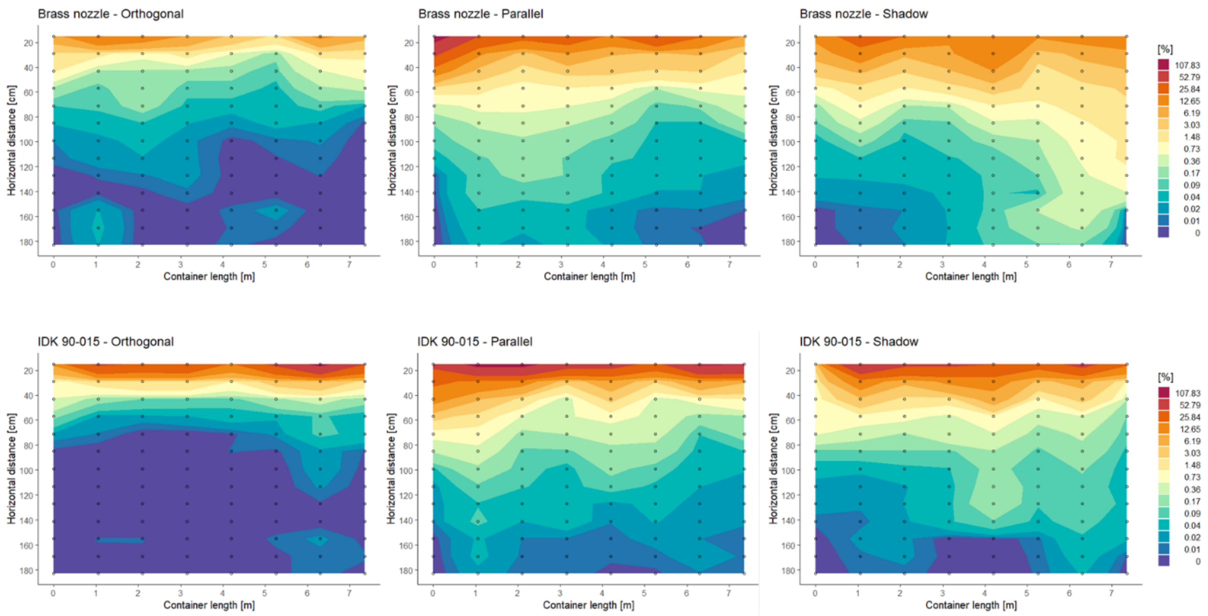
Figure 56: Overview of wind speed during the trials to measure drift in OPM control.



Source: own illustration, JKI

When treating a house wall, the wind direction was a test factor with significant effects. During the treatment of a house wall with a chemical barrier of 50 cm with a knapsack sprayer, the drift values with orthogonal wind direction are significantly lower than the drift values with parallel wind direction and when treating the house wall in the shadow of the wind (Figure 35). Figure 57 shows the surface distribution of the ground sediment as a percentage of the application rate for the three wind directions, orthogonal, parallel and shadow, and the 2 nozzles, brass nozzle and IDK 90-015 C nozzle. It can be clearly seen that irrespective of the nozzle, in the case of orthogonal wind direction the droplets could not drift but were "pressed" against the wall. If the wind direction was parallel or if the house wall was treated in the shadow of the wind, the drops dispersed in front of the treated area without a visible pattern.

Figure 57: Surface distribution of ground sediment in percent of application rate when treating a house wall with a chemical barrier of 50 cm with a knapsack sprayer based on the 50th percentile.

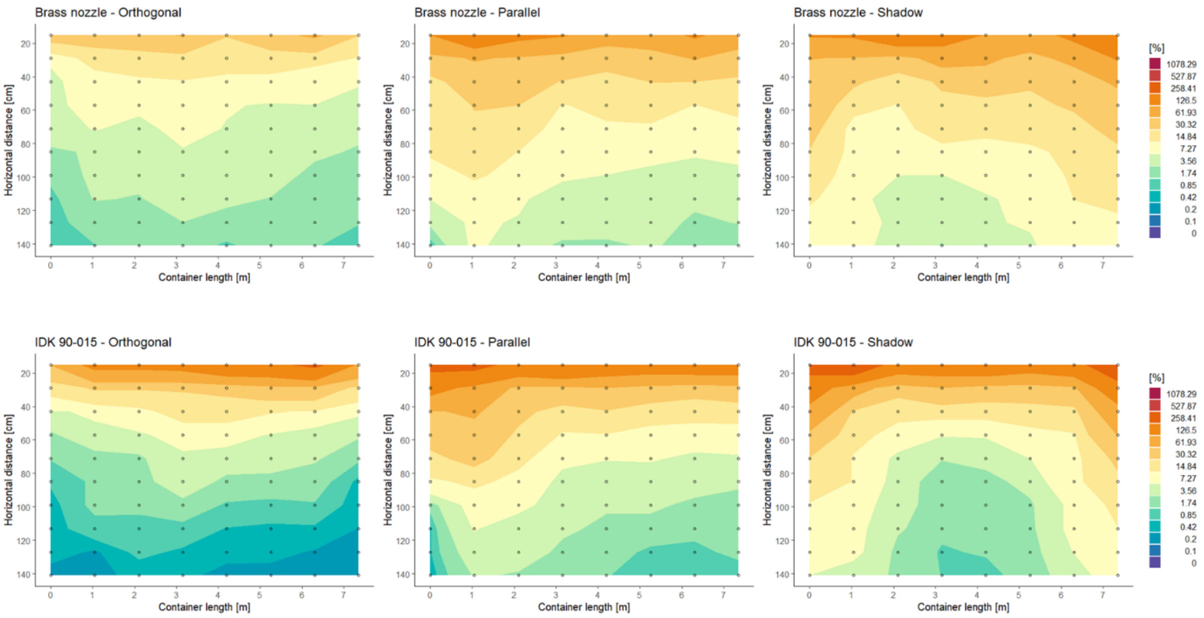


Source: own illustration, JKI

The effect of the orthogonal wind direction during application can also be observed when treating an entire house wall (Figure 58). However, the effect is even stronger when treating a whole house wall than when treating a chemical barrier of 50 cm, as the treated area was also larger. Another effect, which was only observed when treating the entire house wall, is the effect of swirling at the edge of the house wall when treating in the wind shadow. A much higher drift was observed at the two lateral edges than in the middle of the treated area. Therefore, the results were also presented separately in the three areas "entire wall", "edge only" and "without edge".

Considering these two effects, it is very difficult to give an application recommendation based on wind direction. Usually not only one wall of the house is treated, but the whole house. Thus, one side of the wall is always in shadow, the wind is orthogonal or parallel to the wall. A recommendation based on the wind direction would therefore not be practical. However, the results show that when the entire house wall is treated, the choice of nozzle can have an influence on the drift reduction potential (Figure 41).

Figure 58: Surface distribution of ground sediment in percent of application rate when treating an entire house wall with a knapsack sprayer based on the 50th percentile.



Source: own illustration, JKI

4.3.2 Influence of nozzle selection on drift

Drift risk is closely related to droplet size (Hilz & Vermeer 2013) and droplet spectrum (Franke et al. 2010). Droplets of less than 100 µm in diameter are traditionally regarded as prone to drift (de Ruiter et al. 2003; Nuyttens et al. 2007; Arvidsson et al. 2011; Czaczyk et al. 2012; Świechowski et al. 2014; Gregorio et al. 2016; van de Zande et al. 2016; Grella et al. 2020). Nozzle size and spray pressure have a major influence on droplet size (Hilz & Vermeer 2013). While small nozzle orifice produce small droplets, large nozzle orifice produce larger droplets (Hofman & Solseng 2004). Nozzles with larger spray angles produce smaller spray droplets than a nozzle with the same application rate but a smaller spray angle (Hofman & Solseng 2004). However, wide angle nozzles have the advantage that they can be placed closer to the target than narrow angle nozzles (Hofman & Solseng 2004). Overlapping the spray swaths by about 30% results in uniform application and spray coverage (Miller 2003).

Considering these facts makes it difficult to select the "right" nozzle with a low drift potential. In the present trials to control OPM, supposedly very similar nozzles were selected for the drift trials, AirMix 110-05 and ID-120-05 POM. However, already the first trials showed clear differences in the drift, which were confirmed in all further trials. Regardless of the application technique, drift was significantly lower when using the ID-120-05 POM than when using the AirMix 110-05 or the pneumatic cannon sprayer (Figure 25). Thus, on the trial area “avenue” (Figure 26) and on the trial area “forest edge” (Figure 29), a drift mitigation of up to 75% could even be achieved with the ID-120-05 POM compared to the pneumatic cannon sprayer. Both the AirMix 110-05 and the ID-120-05 POM nozzles are flat fan nozzles. The AirMix 110-05 was included in the JKI's list of "loss-reducing devices" in 2002 (BBA 2002), the ID-120-05 POM is a latest generation nozzle and was included in the JKI's list of "loss-reducing devices" in 2015 (JKI 2014). Both nozzles showed no differences in distribution accuracy on the test bench in the laboratory (Figure 48), so that 5 nozzles in conjunction with a distance of 25 cm from each other show a very similar spray pattern. However, there are differences in the droplet size distribution (Figure 50). On the trial area “avenue”, the trials were carried out with a working pressure of

8.0 bar. In this pressure range the AirMix 110-05 shows a VMD of 278.3 µm (50% of the droplets are smaller than 278.3 µm). According to ISO (2018), this corresponds to a droplet size classification of "Medium". The ID-120-05 POM shows a VMD of 310.1 µm (50% of the droplets are smaller than 310.1 µm) in this pressure range and this corresponds to a droplet size classification of "Coarse". It is also noticeable that even with the use of a helicopter and a working pressure of 2.0 bar, similar drift values were observed than with a cannon sprayer and a working pressure of 8.0 bar on the trial area "avenue" (Figure 25). In the pressure range of 2.0 bar, the AirMix 110-05 showed a VMD of 411.7 µm, which corresponds to a droplet size classification of "Very Coarse". The ID-120-05 POM showed a VMD of 664.2 µm in the pressure range of 2.0 bar, which corresponds to a drop size classification of "Ultra Coarse". Considering that drift risk is closely related to droplet size (Hilz & Vermeer 2013) and also to the composition of the droplet spectrum (Franke et al. 2010), the investigations of the nozzles in the laboratory reflect the results of the drift trials in the field, although the investigations in the laboratory are carried out with the conditions of a field sprayer. This means that the distance between the nozzles and the distance to the target object do not correspond to the conditions when controlling OPM with a cannon sprayer.

In the second part of the present project, a house wall and a paved path were treated with a knapsack sprayer. The aim was to measure the drift when a chemical barrier of 50 cm is applied to control crawling insects, when the entire house wall is treated to control flying insects and when treating a paved path. When purchasing a knapsack sprayer, a hollow cone nozzle is normally included as standard. In this case it was a brass hollow cone nozzle with an orifice of 1.7 mm. A hollow cone nozzle has a swirl plate with one or more tangential of helical slots or hole. Liquid is forced through this swirl plate into a swirl chamber. An air core is formed as the liquid passes with a high rotational velocity from the swirl chamber through a circular orifice due owing to the tan genital and axial components of velocity (Matthews et al. 2014). As a comparison to this nozzle, a flat fan nozzle was selected, which has a similar nozzle orifice and flow rate as the brass nozzle. The IDK 90-015 C nozzle was chosen. The laboratory analysis of these two nozzles showed that the spray angle is very similar, but that the distribution of the droplets is very different. While the brass nozzle has a VMD of 208.2 µm at 2.0 bar and is thus classified as "Fine", the VMD of the IDK 90-015 C nozzle is 561.9 µm at 2.0 bar and is classified as "Extremely Coarse" (capture 3.8). These properties are reflected in the drift tests as follows: When applying a chemical barrier of 50 cm to control crawling insects, the lowest drift was measured with the IDK 90-015 C in all three wind directions. The difference was most pronounced when the wind direction was orthogonal. When treating an entire house wall for flying insect control, the drift decreased faster with the IDK 90-015 C nozzle than with the brass nozzle. This pattern was observed for all three wind directions and especially for the applications in the wind shadow, when the wind theoretically has no influence on the drift and only the nozzle properties could be observed. Here, the larger drops of the IDK 90-015 C nozzle fall faster to the ground due to gravity or due to the kinetically greater energy, the rebound is greater and thus increase the values in this area (Hilz & Vermeer 2013) and the smaller drops of the brass nozzle drift further and thus increase the values at the near distance from the treated area. However, it is unclear how much of the measured values is drift, how much is rebound and how far the rebound extends.

Run-off is the proportion of spraying agents that enters the soil through run-off. This proportion should not be underestimated and can strongly influence adjacent environmental compartments. In the OECD ESD, run-off is taken into account with a default value of 20% (OECD 2008). In the present study, a run-off of up to 50% was measured (Figure 44). This run-off can be reduced to less than 1% if the application rate is greatly reduced. Thus, high losses of up to 50% can be minimised if appropriate application rates are recommended for vertical application. Specifications of "1 L application solution for 10 to 20 m²" are not helpful for inexperienced users and conversely imply an application rate of 50 to 100 mL m^{-2}. These studies show that at an application rate of 50 mL m^{-2} the run-off was less than 1% and that at an application rate of 100 mL m^{-2} the run-off was 50%. It is therefore recommended to specify the application rate according to the orientation of the application area. However, it should be noted in the recommendations that these trials were carried out with nozzles that had a very small orifice. Even if the nozzles that were tested showed no difference to each other, it can be assumed that nozzles with a larger opening produce larger droplets, which can lead to unfavourable target coverage (Knoche 1994; de Ruiter et al. 2003; Hofman & Solseng 2004; Franke et al. 2010; Grisso et al. 2019) and even faster run-off (EPA 1998; Czaczyk et al. 2012).

For vertical application, such as when treating a paved path, the difference in drift between the nozzles used is more pronounced. With the IDK 90-015 C nozzle, a drift mitigation of up to 75% was observed compared to the brass nozzle. However, it should be noted that the trials presented here investigate distances that have never been considered in drift tests for plant protection products. In plant protection, drift is measured at distances of 1, 3, 5, 10, 20 and 50 metres, so that the observed drift mitigation and also the classification of the drift mitigation of nozzles takes place under different conditions. This is not comparable with the short distances or high resolutions described here. In addition, these trails show that the spray pattern plays a role in the accuracy of the application. Figure 59 shows the test area "paved path" after treatment with the knapsack sprayer and the brass nozzle and the IDK 90-015 C nozzle. A path with a width of one metre was marked. Keeping to the path width was very difficult with the brass nozzle and was exceeded by 10 cm. This also explains the high drift of up to 90% in the first collector on the measuring area of the brass nozzle. However, this was only visible after application, when the fine droplets sedimented onto the ground. With the IDK 90-015 C nozzle, a much clearer and easier handling was possible. The laboratory analyses of the distribution accuracy indicate these conditions. Figure 47 shows the distribution accuracy of the brass nozzle at different pressures. At 2.0 bar, the measuring nozzle runs out very softly. This effect is even stronger at higher pressures of 3.0, 5.0 and 7.0 bar. The literature also shows that hollow cone nozzles are generally used for applications where complete coverage of the leaf surface is important. The finer the droplet of the nozzle, the better the coverage (Hofman & Solseng 2004) and they produce a fine spray that is concentrated on the outer edge of the pattern (Miller & Bellinder 2001; Franke et al. 2010; ISO 2020).

Figure 59: Trial area "paved path" after application with a knapsack sprayer and a brass nozzle (left) and an IDK 90-015 C nozzle (right).

Source: JKI

4.4 Nozzle recommendation for OPM controlling

In chapter 0, the effects of nozzles on drift were shown to be high. When using a cannon sprayer with ID-120-05 POM nozzle, a drift mitigation of 75% was possible compared to a pneumatic cannon sprayer. The question is now, which nozzles have similar characteristics regarding drift to the ID-120-05 POM nozzle and therefore could be classified in one assortment for a general nozzle recommendation.

The JKI's "List of loss-reducing devices" (JKI 2022c) is based on field and wind tunnel trials and has been developed from over 30 years of experience. The trials for field crops were carried out with a distance to target of 50 cm as a determination of use. According to this, ID-120-05 POM is registered as follows: 90% drift mitigation up to 3.0 bar, 75% drift mitigation up to 6.0 bar and 50% drift mitigation up to 8.0 bar. The ID-120-05 POM nozzle is recognised in the pressure range from 2.0 to 8.0 bar.

The "List of Loss Reducing Devices" includes both flat fan and double flat fan nozzles with nozzle sizes ranging from 025 to 06. According to this list, 41 nozzles have been classified with a drift reduction of 90% at 2.0 bar, 22 nozzles with a drift reduction of 90% at 2.5 bar and 18 nozzles with a drift reduction of 50% at 8.0 bar (as of May 2022). In addition, 9 nozzles have been classified with a drift reduction of 75% at 8.0 bar and 2 nozzles with a drift reduction of 90% at 8.0 bar and have thus been classified better than the ID nozzle. But be careful, not all of these nozzles can be used equally for all devices. It should be noted that a change in nozzle size always goes along with an alteration in flow rate, since that affects the amount of water. In the approval of biocidal products or pesticides in general, the amount of water plays an important role. As an example: For the biocidal product "Foray ES" applications are approved with the following amounts of water (L water ha^{-1}):

- Cannon sprayer as trailed device: 3 L ha^{-1} in 600 L water ha^{-1}.
- Helicopter as aerial spraying, 3 L ha^{-1} in at least 35 L water ha^{-1} (BAuA 2017).

The following tables (Table 23, Table 24 and Source: own compilation, JKI

Table 25) show the different amount of water when the nozzle size is changed and all other settings are unchanged with a cannon sprayer on the trial area "avenue" and with a helicopter on the trial areas "avenue" and "forest edge". Nozzles of size 05 were used in the present study. These nozzles have a flow rate of 3.22 L min^{-1}. Depending on the equipment settings, this corresponded to an amount of water of 411.1 L ha^{-1} with a cannon sprayer on the trial area "avenue", 36.5 L ha^{-1} with a helicopter on the trial area "avenue" and 40.8 L ha^{-1} with a helicopter on the trial area "forest edge" (marked in grey in the tables). Table 23 shows a change in the amount of water when the nozzle size changes and when using a cannon sprayer on the trial area "avenue" at 8.0 bar. If smaller nozzles with a flow rate of 1.94 L min^{-1} are used, the amount of water is reduced to 247.7 L ha^{-1}. If larger nozzles with a flow rate of 3.86 L min^{-1} are used, the amount of water is increased to 492.8 L ha^{-1} (Table 16). A smaller as well as a larger nozzle leads to a reduction and an increase of the amount of water, but the values remain within the approved range for the example biocidal product.

Table 23: Amount of water with different nozzle sizes and flow rates using a cannon sprayer on the trial area “avenue”. Size 05 was tested in the present study.

Nozzle size	03	04	05	06
Flow rate [L min^{-1}]	**1.94**	**2.58**	**3.22**	**3.86**
Pressure [bar]	8	8	8	8
Speed [km h^{-1}]	1.6	1.6	1.6	1.6
Nozzle spacing [m]	--	--	--	--
Number of nozzles in the nozzle ring	8	8	8	8
Number of nozzles on boom	--	--	--	--
Working width [m]	23.5	23.5	23.5	23.5
Amount of water [L ha^{-1}]	**247.7**	**329.4**	**411.1**	**492.8**

Source: own compilation, JKI

Table 24 shows the change in the amount of water applied when the nozzle size is changed and when a helicopter is used on the trial area "avenue" at 2.0 bar. If smaller nozzles with a flow rate of 0.81, 0.97 and 1.29 L min^{-1} are used, the amount of water applied is reduced to 18.4, 22.0 and 29.2 L ha^{-1} respectively. Thus, if a smaller nozzle is used than was used in the present study, the amount of water applied falls below the permitted range for the biocidal product example. If a larger nozzle with a flow rate of 1.93 L min^{-1} is used, the amount of water applied increases to 43.7 L ha^{-1} and the amount of water applied is above the permitted range for the example biocidal product. (Table 24). A similar behaviour can be seen when using a helicopter on the trial area "forest edge" with 2.5 bar (Table 25). If smaller nozzles with a flow rate of 0.91 and 1.08 L min^{-1} are used, the amount of water applied is reduced to 20.6 and 24.5 L ha^{-1} respectively. Here, too, the amount of water applied falls below the permitted amount of water for the example biocidal product if a smaller nozzle is used than the one used in the present study. The use of a larger nozzle with a flow rate of 1.8 L min^{-1} does not pose a problem. The amount of water applied with this nozzle size increases to 40.8 L ha^{-1}, which is above the approved range for the example biocidal product.

Table 24: Amount of water with different nozzle sizes and flow rates using a helicopter on the trial area “avenue”. Size 05 was tested in the present study.

Nozzle size	025	03	04	05	06
Flow rate [L min^{-1}]	0.81	0.97	1.29	1.61	1.93
Pressure [bar]	2	2	2	2	2
Speed [km h^{-1}]	60	60	60	60	60
Nozzle spacing [m]	0.15	0.15	0.15	0.15	0.15
Number of nozzles in the nozzle ring	--	--	--	--	--
Number of nozzles on boom	34	34	34	34	34
Working width [m]	15	15	15	15	15

Nozzle size	025	03	04	05	06
Amount of water [L ha-1]	**18.4**	**22.0**	**29.2**	**36.5**	**43.7**

Source: own compilation, JKI

Table 25: Amount of water with different nozzle sizes and flow rates using a helicopter on the trial area “forest edge”. Size 05 was tested in the present study.

Nozzle size	025	03	05	06
Flow rate [L min-1]	0.91	1.08	1.8	2.16
Pressure [bar]	2.5	2.5	2.5	2.5
Speed [km h-1]	60	60	60	60
Nozzle spacing [m]	0.15	0.15	0.15	0.15
Number of nozzles in the nozzle ring	--	--	--	--
Number of nozzles on boom	68	68	68	68
Working width [m]	30	30	30	30
Amount of water [L ha-1]	**20.6**	**24.5**	**40.8**	**49.0**

Source: own compilation, JKI

In summary, when choosing a nozzle, it is necessary to check the properties of the nozzle and the approved amount of water for the product in question. The following three tables list the nozzles that have the same drift classification in field crops as the ID-120-05 POM based on their entries in the List of Loss Reducing Devices (Table 26, Table 27 and Table 28, status Mai 2022). Table 29 and Table 30 list the nozzles that have with 75% und 90% a higher drift mitigation at 8.0 bar and thus perform even better than the ID-120-05 POM nozzles.

Table 26: Nozzles with 90% drift mitigation at 2.0 bar under the specification of nozzle sizes, flow rates and manufacturers.

Nozzle sizes	Flow rates [L min-1]	Nozzles	Manufactures
025	0.81	ID-120-025 POM	Lechler
		ID-120-025 C	
		IDN 120-025 POM	
		IDTA 120-025 C	
		PSULDCQ20025	John Deere
		PSAULDCQ20025	
03	0.97	ID-120-03 POM	Lechler
		ID-120-03 C	
		IDN 120-03 POM	
		IDTA 120-03 C	

Nozzle sizes	Flow rates [L min⁻¹]	Nozzles	Manufactures
		PSULDCQ2003	John Deere
		PSAULDCQ2003	
		TTI60-110 03 VP-C	TeeJet
04	1.29	TurboDrop HiSpeed 110-04	AGROTOP
		SoftDrop 110-04	
		8 MS 110 04 C	Agroplast
		ID-120-04 POM	Lechler
		ID-120-04 C	
		PSULDCQ2004	John Deere
		TTI 110 04 VP	TeeJet
		TTI60-110 04 VP-C	
		APTJ-11004VP	
05	1.61	8 MS 110 05 C	Agroplast
		SoftDrop 110-05	AGROTOP
		ID 120-05 C	Lechler
		ID 120-05 POM	
		ID-120-05 POM	
		ID-120-05 C	
		PSULDCQ2005	John Deere
		AIC 110 05 VP	TeeJet
		AIC 110 05 VS	
		AI 110 05 VS	
		TTI 110 05 VP	
		TTI60-110 05 VP-C	
		UR110-05	Wilger
06	1.93	ID-120-06 POM	Lechler
		ID-120-06 C	
		TTI 110 06 VP	TeeJet
		AITTJ60 11006 VP	
		APTJ-11006VP	
		UR110-06	Wilger

Source: own compilation, JKI

Table 27: Nozzles with 90% drift mitigation at 2.5 bar under the specification of nozzle sizes, flow rates and manufacturers.

Nozzle sizes	Flow rates [L min^{-1}]	Nozzles	Manufactures
025	0.91	TurboDrop HiSpeed 110-025	Agrotop
		ID-120-025 POM	Lechler
		ID-120-025 C	
		PSULDCQ20025	John Deere
03	1.08	ID-120-03 POM	Lechler
		ID-120-03 C	
		PSULDCQ2003	John Deere
		TTI60-110 03 VP-C	TeeJet
05	1.80	SoftDrop 110-05	Agrotop
		ULD 05	Hypro
		PSULDQ2005A	John Deere
		ID-120-05 POM	Lechler
		ID-120-05 C	
		PSULDCQ2005	John Deere
		AIC 110 05 VP	TeeJet
		AIC 110 05 VS	
		AI 110 05 VS	
06	2.16	ID-120-06 POM	Lechler
		TTI 110 06 VP	TeeJet
		AITTJ60 11006 VP	
		APTJ-11006VP	
		UR110-06	Wilger

Source: own compilation, JKI

Table 28: Nozzles with 50% drift mitigation at 8.0 bar under the specification of nozzle sizes, flow rates and manufacturers.

Nozzle sizes	Flow rates [L min^{-1}]	Nozzles	Manufactures
03	1.94	ULD 03	Hypro
		ID 120-03 C	Lechler
		ID 120-03 POM	
		ID-120-03 POM	

Nozzle sizes	Flow rates [L min^{-1}]	Nozzles	Manufactures
		ID-120-03 C	
		IDN 120-03 POM	
		PSULDQ2003A	John Deere
		PSULDCQ2003	
		AIC 110 03 VP	TeeJet
		AIC 110 03 VS	
		AI 110 03 VS	
04	2.58	AVI 110-04	AGR
		ID-120-04 POM	Lechler
		ID-120-04 C	
		PSULDCQ2004	
05	3.22	TurboDrop HiSpeed 110-05	AGR
		ID-120-05 POM	Lechler
06	3.86	ID-120-06C	Lechler

Source: own compilation, JKI

Table 29: Nozzles with 75% drift mitigation at 8.0 bar and thus performing better than the ID-120-05 POM nozzle under the specification of nozzle sizes, flow rate and manufacturers.

Nozzle sizes	Flow rates [L min^{-1}]	Nozzles	Manufactures
04	2.58	ULD 04	Hypro
		PSULDQ2004A	John Deere
05	3.22	ID 120-05 C	Lechler
		ID 120-05 POM	
		ID-120-05 C	
		Syngenta 130-05	
		PSULDCQ2005	John Deere
06	3.86	ID-120-06 POM	Lechler
		AITTJ60 11006 VP	TeeJet

Source: own compilation, JKI

Table 30: Nozzles with 90% drift mitigation at 8.0 bar and thus performing better than the ID-120-05 POM nozzle under the specification of nozzle sizes, flow rate and manufacturers.

Nozzle sizes	Flow rates [L min^{-1}]	Nozzles	Manufactures
05	3.22	ULD 05	Hypro
		PSULDQ2005A	John Deere

Source: own compilation, JKI

5 Conclusion

As the previous project already indicated, the question posed at the beginning as to whether the basic drift values from plant protection can be transferred to biocide application can clearly be answered with "no". A transfer of the basic drift values from the equipment for the application of plant protection products to the biocide sector proved to be impossible, since no application scenario from the plant protection sector corresponded to the scenarios from the biocide sector. The application areas and the equipment used are too different and led to different basic drift values. It should be noted that the basic drift values for plant protection were derived from over 100 trials and the derivation of basic drift values for the biocide area in this project and its predecessor are only the first trials ever in this area. It is therefore recommended to establish in the future specific basic drift values for each application area and for each equipment until the database is sufficiently large. But already now with these trials it has been made clear that there are alternative application possibilities that have a much lower drift potential than the "standard methods". These include the change from a pneumatic cannon sprayer to a hydraulic cannon sprayer with drift-reducing nozzles of the latest generation or the change from hollow cone nozzles to flat spray nozzles when using knapsack sprayers. The results of the run-off trials also showed that the recommended spray rates might result in significant losses of up to 50% that could easily be minimized by indicating appropriate application volumes.

Furthermore, it is recommended to establish specific guidelines for measuring drift. For the trials conducted in the project, the JKI guideline 7-1.5 for measuring direct drift when applying liquid plant protection products in the field (JKI 2013b) was applied. It turned out that this guideline can be applied with a few optimisations for the measurement of drift when applying liquid biocides for the control of the oak processionary moth in the field, but the optimisations should also be incorporated in a separate guideline. Furthermore, there is no guidance for measuring drift when treating house walls and pathways.

The OECD's default values from its ESD should be adapted for a risk assessment. As only one default value is given, considerable misinterpretations can occur if, as in the present project, a nozzle is used whose coarse droplets sediment early or rebound greater and indicate a high drift value in the near distance to the treated area, but the nozzle has few fine droplets that cannot drift far. And in contrast, a nozzle is used that has few large drops and thus shows a low drift in the close distance, but instead has many fine drops that show a high drift at a greater distance from the treated area. It is therefore recommended to specify basic drift values of at least 5 distances in accordance with the JKI guideline 7-1.5 in order to evaluate the trials comparably and to be able to carry out a more meaningful exposure assessment.

6 Excursus - ULV application techniques for mosquito control

6.1 Definition

In the 1960s of the 20th century, the first attempts with undiluted formulations of liquid insecticides for insect control were conducted (Messenger 1963; Messenger 1964; Skoog et al. 1965; Wilson et al. 1965). After several years of research and development, the term "ultralow volume" or "ULV" began to be widely used to describe the application of undiluted insecticide formulations (Mount et al. 1996). However, there are still very different interpretations of ULV to this day. According to Bonds (2012) ULV describes the application of undiluted pesticides, using a minimally effective volume in very fine droplets. Lofgren (1970) and Sayer (1959) describe the application of 1.5 liters or less per hectare as ULV. According to the U.S. Environmental Protection Agency (EPA 1998), ULV refers to a total volume of 1.89 liters or less per hectare. Often, ULV is also used as a synonym for devices or technologies that make it possible to apply amounts of less than 5 L ha^{-1} (Craig et al. 2014; Matthews et al. 2014; WHO 2018; Martelloni et al. 2020). In this context, terms such as ULV aerosol generator (Piccolomini et al. 2018) or ULV sprayer (Ferguson et al. 2016) are also used. Clarity regarding the meaning of the term ULV is provided by the ISO 5681:2020 standard from the International Organization for Standardization "Equipment for crop protection - Vocabulary" (ISO 2020), which was released in 2020. In this guideline, ULV is defined as an application where, in general, less than 5 L ha^{-1} is applied for field crops and less than 50 L ha^{-1} for shrub and tree crops. Whether the substance is applied undiluted or diluted, with which device, and in what droplet spectrum the substance is applied, is not described. The definition solely refers to the area-based application quantity.

6.2 Introduction

The low application rate of less than 5 L ha^{-1} implies the use of an undiluted substance in very fine droplets. Therefore, ULV applications, according to Matthews et al. (2014) , offer the possibility to employ this approach frequently in areas where water is a limiting factor. For instance, ULV is utilized in combating locusts in arid regions (Holland & Jepson 1996), addressing sand flies in equatorial Kenya (Britch et al. 2011) and Libya (Dokhan et al. 2017) and controlling tsetse flies in Zimbabwe (Johnstone et al. 1987). However, ULV is also of significant importance in mosquito control (Mount et al. 1996; Mount 1998; Hoffmann et al. 2007; Hoffmann et al. 2009; Britch et al. 2010; Bonds 2012; de Rudnicki et al. 2012; Farajollahi et al. 2012; Al-Sarar et al. 2014; Boubidi et al. 2016; Piccolomini et al. 2018; AFPMB 2019; Dzul-Manzanilla et al. 2019).

In vector control, both ground and aerial applications have been the standard method worldwide for over 60 years (Lofgren 1970; Mount 1998; Bonds 2012). Droplet size plays a significant role in effective vector control (Ali et al. 2011). The average droplet size ranges from 8 to 30 µm in diameter. Smaller droplets remain suspended in the air for longer periods, increasing the likelihood of contact with mosquitoes (Schleier III et al. 2012; Piccolomini et al. 2018). Several studies have shown that the optimal droplet size should be less than 20 µm in diameter for the applied substance to be effective (Bonds 2012). Using scanning electron microscopy, Lofgren et al. (1973) found that droplets with diameters of 2 to 16 µm impacted the wings and antennae of mosquitoes flying through an aerosol cloud. Droplets with diameters of up to 32 µm were found on surfaces, but they were not observed on mosquitoes (Lofgren et al. 1973).

However, the success of vector control is determined not only by droplet size but also by the choice of the employed technique. Boubidi et al. (2016) investigated the efficacy of ULV and thermal aerosols for controlling *Aedes albopictus* (Asian tiger mosquito) in Nice, France. The vehicle-mounted cold fogging device 18-20 from London Foggers (London Foggers, Long Lake, MN, USA) was used as the ULV device. The portable thermal fogging device K-10-SP from pulsFOG (pulsFOG Dr. Stahl & Sohn GmbH, Germany) served as the comparative device. They found that ULV aerosols were not effective in reducing the number of eggs and females, as well as the female parity rate, whereas, in contrast, treatment with thermal fogging reduced egg laying and the capture of adult insects by approximately 61% to 95%. They attribute the poor performance of ULV aerosols to the fact that vectors prefer resting places, especially in vegetation where there is no air movement, while aerosols rely on air movement to reach the vectors. Similarly, the effectiveness of a vehicle-mounted device, especially in urban areas where walls, buildings, and other structures hinder particle drift, can be greatly limited. In contrast, with the portable thermal fogging device, the aerosol was applied up close to the suspected resting places, guided by the operator, and enhanced by the physical thrust of the machine's exhaust energy. Boubidi et al. (2016) conclude that in the case of disease outbreaks, a truck-mounted ULV application is likely to have no significant impact on transmission. However, thermal or ULV aerosols from portable sprayers are the method of choice, even though they are labor-intensive.

Bonds (2012) states that regardless of the technique, the timing of the intervention is crucial for the success of vector control. A substance can only be effective if the target is hit, and in this case, the target is the wings of the vectors. Therefore, control efforts should occur during the most active phase of the vectors, specifically during their host-seeking behavior. Targeting vectors at their resting places, as observed by Boubidi et al. (2016), is therefore not considered productive. For successful vector control, precise identification of the vector and consideration of meteorological conditions at the time of application are essential parameters (Bonds 2012). These parameters can vary greatly depending on the mosquito species. Mosquito species like *Aedes melanimon*, *Culex tarsalis* and *Culex quinquefasciatus* exhibit their highest host-seeking activity 1 to 2 hours after sunset from May to June and September to October. However, during July and August, when evening air temperatures become warmer, the peak host-seeking activity shifts by 1 to 4 hours (Meyer et al. 1986). *Culex salinarius* mosquitoes are most active within 2 hours after sunset, with host-seeking activity diminishing significantly during the rest of the night and showing no increase in activity before sunrise (Slaff & Crans 1981). Additionally, *Culex nigripalpus* mosquitoes are crepuscular and nocturnal, being most active during the 3 hours after sunset and just before sunrise (Day & Curtis 1994). In contrast, *Aedes aegypti* und *Aedes albopictus* mosquitoes are diurnal. They typically peak in activity in the hours after sunrise and before sunset, with reduced or minimal activity during the heat of the day and little to no activity at night (Chadee 1988). However, the timing of control efforts depends not only on the time of day but also on meteorological events that can influence vector flight activity. For instance, the primary transmitter of West Nile virus (WNV) and St. Louis encephalitis virus (SLE) in Florida, *Culex nigripalpus*, is highly responsive to meteorological changes. Its activity increases with higher humidity and temperature. Elevated wind speeds, on the other hand, lead to reduced activity, while moonlight enhances the activity of this mosquito species (Day & Curtis 1994).

6.3 Requirements for vector control equipment

The choice of the right technique strongly depends on the specific application area (Britch et al. 2010). The types of equipment range from small aerosol dispensers (pressurized containers) capable of treating relatively small areas to larger machines suitable for outdoor use. These include thermal and cold fogging devices that can be carried by hand or mounted on vehicles for widespread treatments. While a general framework for the design of pesticide application machinery does exist, it is explicitly noted that this framework applies only to pesticides that are plant protection products and not to biocides (EU 2009). In collaboration with independent experts and pesticide application equipment manufacturers, the World Health Organization (WHO) has developed a document outlining the design and specifications of equipment for vector control (WHO 2018). The specifications described for vector control equipment largely align with the specifications for plant protection product application equipment as defined by JKI (2013c), particularly those pertaining to misting devices (Device Category 7). Some spraying devices can theoretically be employed in both fields.

- Material: All materials used in the construction of the equipment must be corrosion-resistant and must not wear or impair the normal operation of the equipment during regular use.
- Design: The spraying apparatus must be designed so that external surfaces do not enclose or retain spray liquid. All attached fittings must not have sharp edges or protrusions that could potentially harm the operator during normal operation.
- Weight: The maximum weight of the spraying device must not exceed the weight specified in national health and safety regulations (portable devices 25 kg (in backpack) or 20 kg (in hand), vehicle-mounted devices up to 250 kg).
- Leakage: All devices must be constructed in a way that prevents pesticides from leaking out.
- Formulation tank capacity: The size of the tank for handheld devices should be determined by the maximum weight a user can carry. For mechanized devices, the tank size should be based on the operating time of the engine relative to normal operational requirements. The pesticide container must be designed for complete emptying.
- Formulation tank labeling: The tank must be marked with permanent indicators at intervals of 1 liter for tanks up to 10 liters capacity and at intervals of 5 liters for larger tanks.
- Formulation tank opening and filter: The tank should have an opening of at least 90 mm in the minor axis. This is to enable fast filling without spillage or splashing. The filling opening must have a filter that is deep enough to prevent splashing.
- Straps (on handheld equipment): One or two shoulder straps (for backpacks) must be attached. A lever-operated spraying device should also have a waist strap. The strap width should be at least 50 mm, and it must be adjustable in length.
- Hose: The hose must withstand double the recommended maximum working pressure of the pesticide or air.
- Droplet spectrum: The requirements for the droplet spectrum depend on the type of spray desired. The droplets must have a Volume Median Diameter (VMD) of <30 µm to remain suspended in the air longer. The nozzle output depends on the construction of the spraying device and must be specified based on the application type and the equipment the nozzle is attached to.

- Noise level for devices with gasoline engines and other motorized devices: If the noise level measured at the operator's ear exceeds 85 dB, hearing protection must be available and used.
- Labels: The manufacturer's name and contact information, machine type, manufacturing date or serial number, and the location of key components relevant to the routine use of the device must be easy to locate and identify. The position of valves or switches indicating on/off positions, nozzle size or flow restrictor, and the position of other controls must be clearly visible.
- User manual: The equipment must come with a clear, simple, and illustrated operating manual that explains the operational procedures, including calibration methods, safety precautions, maintenance procedures, and the replacement parts required for routine maintenance.
- Field use: The user should record the application on a spraying equipment history card.

6.4 Vector Control Equipment

In addition to the general requirements for vector control equipment, WHO also provides device-specific specifications (WHO 2018). The following outlines the WHO device-specific specifications and provides an overview of devices that are potentially suitable for vector control in outdoor environments. There is no comprehensive overview or database of all types of devices available in the market. The listing of devices is based on internet research and information from respective data sheets, referenced for accuracy. Therefore, no guarantee of the completeness of devices available in the market is given, and this listing does not represent an evaluation. This list aims to provide a broad informational offering.

6.4.1 Motorised Knapsack Sprayers

Motorized knapsack sprayers are used for the rapid treatment of open water bodies for larval control in urban areas and for treating house roofs and foliage as a barrier treatment to reduce the number of mosquitoes entering houses. It must be equipped with a motor-driven blower generating a high-velocity air stream, into which pesticide liquid is metered and sprayed upward into trees for at least 10 meters.

Furthermore, the motor must feature a simple starting mechanism. A fuel tank must be mounted below the motor. All moving parts and the exhaust must be protected to prevent burn injuries. Motor controls, including a kill switch and throttle control, must be positioned visibly for the user during operation. The knapsack frame should have a non-absorbent, padded backrest to comfortably rest the knapsack on the user's back. The attachment must dampen motor vibrations during normal operation. All parts regulated during device operation must be durably and distinctly marked.

Additionally, the sprayer must be equipped with a two-stroke or four-stroke engine weighing less than 12 kg. The fuel tank capacity must allow operation for at least one hour without shutting off the engine. Fuel consumption must be <2 liters per hour when operating the engine at optimal RPM. Fuel type and mixture must be permanently indicated on the fuel tank, filler cap, or machine.

An air shear or rotary atomizer can be attached to generate droplets with a Volume Median Diameter (VMD) in the range of 50-100 µm. Some sprayers come with a very small flow restrictor, resulting in a VMD <50 µm. During research, manufacturers were found to offer "ULV nozzles" specifically for vector control, providing a very fine droplet spectrum (SOLO 2021; Tomahawk 2023c). Additionally, the manufacturer STIHL offers a ULV nozzle as an accessory. However, this nozzle consists only of a filter and a dosing knob that reduces the system's flow rate to as low as 0.04 liters per minute (STIHL 2020b).

Table 31: The models 466 by SOLO, Port 423 by iGEBA, AU8000 by MiCRON and BM100 by Vector Fog.

Model	SOLO 466	iGEBA Port 423	MiCRONAIR AU8000	Vector Fog BM100
				
Power (HP)	2.9	4.1	4.1	2.6
Droplet spectrum (µm)	VMD 40-51	VMD < 30	40-200	< 60
Flow rate (L h^{-1})	2.4-10.5	2-6	4.2-72	
Formulation tank (L)	14	12	12	16
Fuel tank (L)	1.4	1.4	1.4	1.3
Weight (kg)	10	11.5	10.7	10.6
Dimension (cm)		68 x 45 x 34	30 x 15	41.5 x 50.5 x 71
Reference	SOLO (2021); SOLO (2022)	iGEBA (2016)	Micron Group (2023a)	Vector Fog (2020)

Source: own compilation, JKI

Table 32: The models 6l and 11l ULV nebulisers by Guarany and Pulmic Taurus AIR+ by Grupo Sanz.

Model	Guarany 6l ULV Knapsack Nebuliser	Guarany 11l ULV-LV Nebuliser	Grupo Sanz Pulmic Taurus AIR+
			
Power (HP)	4.6	4.6	5.3
Droplet spectrum (µm)			
Flow rate (L h^{-1})	15	36	1
Formulation tank (L)	6	11	14
Fuel tank (L)	2	2	1.3
Weight (kg)	11.5	12.5	12
Dimension (cm)	50 x 41.5 x 61	55 x 40 x 65	44.5 x 54 x 69
Reference	Guarany (2023a)	Guarany (2023b)	Grupo Sanz (2019f)

Source: own compilation, JKI

Table 33: The MM300 Mister and MM181 ULV Fogger models by Maruyama and TMD14 and eTMD14 by Tomahawk.

Model	Maruyama MM300 Mister	Maruyama MM181 ULV Fogger	Tomahawk TMD14	Tomahawk eTMD14
				
Power (HP)	2	4.3	3	Li-Ion battery
Droplet spectrum (µm)	VMD 55-64		25-100	100-300
Flow rate (L h^{-1})	0-180	228		56-113
Formulation tank (L)	15	13	14	15.14
Fuel tank (L)	0.5	2	1	--
Weight (kg)	7.1	11.2	15.9	8.16
Dimension (cm)	34.5 x 39.5 x 60	37.5 x 48 x 59	53.5 x 43.8 x 66	38.1 x 33 x 55.9
Reference	Maruyama (2017b)	Maruyama (2017a)	Tomahawk (2023a)	Tomahawk (2023b)

Source: own compilation, JKI

Table 34: The models SR 430, SR 450 and SR 200 by Stihl

Model	Stihl SR 430	Stihl SR 450	Stihl SR 200
			
Power (HP)	3.9	3.9	1.1
Droplet spectrum (µm)			
Flow rate (L h^{-1})	2.4-7.2	2.4-7.3	9-22.2
Formulation tank (L)	14	14	10
Fuel tank (L)	1.7	1.7	1.05
Weight (kg)	12.2	12.8	7.9
Dimension (cm)			
Reference	STIHL (2020b)	STIHL (2020b)	STIHL (2020a)

Source: own compilation, JKI

6.4.2 Portable Cold Fogging Devices (Aerosol Generators)

Portable or handheld cold fogging devices are used for space treatment in buildings, houses, and outdoor locations inaccessible to vehicles. They must be equipped with a motor featuring a simple starting mechanism. Electrically powered devices suitable for indoor use must meet the same requirements.

Furthermore, the fuel tank must be positioned below the motor. The motor controls required for operation, along with a motor stop switch, must be positioned in a way visible to the operator. The motor-blower unit must be mounted on a knapsack frame designed for comfortable carrying. The attachment system must dampen vibrations. The knapsack frame must have a non-absorbent, padded backrest, and all parts regulated during device operation must be durably and visibly marked.

Additionally, the fuel tank capacity must allow field operation for at least one hour without engine shutdown. Fuel type and mixture must be permanently indicated on the fuel tank, filler cap, and the machine. The formulation tank capacity must be at least 1 liter and feature a clear gauge for displaying the liquid volume in the container. A built-in filter or funnel filter must be provided with the device unless a ready-to-use container is used. If the container is under pressure of more than 50 kPa, a device must be present to fully release pressure from the container before opening.

A swirling nozzle is provided to break down the spray into droplets with a VMD <30 µm at the recommended performance for water and oil-based formulations. The liquid flow to the nozzle must be regulated by a fixed but replaceable throttle or by a control valve placed before the nozzle. Flow rate settings must be labeled on the valve or throttle location.

Table 35: The models Colt4 by London Foggers, Bullet by Arro-Gun, Twister XL by Curtis Dyna-Fog, Pioneer by Longray and Fontan Portastar by Swingtec.

Model	London Foggers Colt4	Arro-Gun Bullet	Curtis Dyna-Fog Twister XL3	Longray Pioneer	Swingtec Fontan Portastar S
					
Power (HP)		1.63		2	Li-Ion battery
Droplet spectrum (µm)	$D_{v0.9}$ < 15	1-60	$D_{v0.9}$ < 20	VMD < 30	5.0-50
Flow rate (L h^{-1})			2.7	1-17	0-21
Formulation tank (L)	9.46	0.5	3.7	3	6
Fuel tank (L)	0.59	0.52	0.5	1	--
Weight (kg)	9.2	6	11.8	12.8	10.3
Dimension (cm)	35.6 x 29.2 x 34.3	39.4 x 29.2 x 38.1	14.7 x 12 x 22,5	41 x 43 x 48	33.3 x 32.8 x 50.5
Reference	London Foggers (2022c)	Arro-Gun (2023)	Curtis Dyna-Fog (2016g)	Longray (2023c)	Swingtec (2019b)

Source: own compilation, JKI

6.4.3 Vehicle-Mounted Cold Fogging Devices

A vehicle-mounted cold fogging device is an aerosol-generating machine that can be mounted on a pickup truck or trailer, a boat, an amphibious vehicle, or a drone. Vehicle-mounted cold fogging devices are used for treating outdoor surfaces where no residual spray remains. Some of these cold fogging devices are used for barrier treatments and for applying liquid larvicides when droplet size can be increased. The various components of the cold fogging apparatus must be mounted on a corrosion-resistant frame that fits an appropriate vehicle.

Furthermore, a formulation tank and an additional flushing tank must be present. The device must be equipped with a suitable control system operable from the vehicle cab, and it must have a fuel tank with sufficient capacity to operate the spraying device for at least 2 hours. All individual tanks must be durably and visibly labeled and have a draining mechanism. The exhaust and moving parts of the engine must be shielded to prevent injuries. The engine must be equipped with a timer (hour meter).

Additionally, the formulation tank capacity must be at least 50 liters. The fuel type must be clearly indicated on the fuel tank filler cap, and all devices must be equipped with manual flow control that can be set to a fixed position. A shut-off valve must be provided that automatically closes when a part of the device is turned off or ceases functioning. If a pressure system with more than 50 kPa (0.5 bar) is used in the setup, an automatic pressure relief device must be present. The nozzle must deliver a droplet size of no more than 30 µm VMD at the optimal operating parameters and flow rates for the formulations to be used. In devices that allow for droplet size adjustment, larger droplets can be selected for specific applications. The remote control panel in the vehicle cab must be equipped with permanently labeled switches for turning off the machine and for turning the pesticide flow on and off.

Table 36: The models LECO 1800E, Cougar, Grizzly and Pro-Mist Dura by Clarke.

Model	clarke LECO 1800E	clarke COUGAR®	clarke GRIZZLY®	clarke PRO-MIST® DURA
				
Power (HP)	18	10	18	12 volt battery
Number of nozzle	1	1	1	1
Droplet spectrum (µm)				
Flow rate (L h^{-1})	32	32	32	
Formulation tank (L)	56.7	56.7	56.7	56.7
Flush tank (L)	3.8	1.9	3.8	
Fuel tank (L)	4.5	10.7	38.8	--
Weight (kg)	216	112	216	46 + battery
Dimension (cm)	121.9 x 99 x 91.4	107 x 91 x 102	137 x 107 x 107	107 x 71 x 94
Reference	Clarke (2023)	Clarke (2022)	Clarke (2022)	Clarke (2022)

Source: own compilation, JKI

Table 37: The models 18-20, 9-10 and M.A.G. by London Foggers

Model	London Foggers 18-20	London Foggers 9-10	London Foggers M.A.G.
			
Power (HP)	19	18	5.5
Number of nozzle	1	1	1
Droplet spectrum (µm)	$D_{v0.8} < 20$	$D_{v0.8} < 20$	$D_{v0.8} < 20$
Flow rate ($L\ h^{-1}$)			0-17.7
Formulation tank (L)	56	56	9.46
Flush tank (L)	1.43	1.43	
Fuel tank (L)	22.7	28.38	4.1
Weight (kg)	202	202	51
Dimension (cm)	94 x 117 x 99	94 x 117 x 99	71.1 x 45.7 x 53.3
Reference	London Foggers (2022b)	London Foggers (2022a)	London Foggers (2022e)

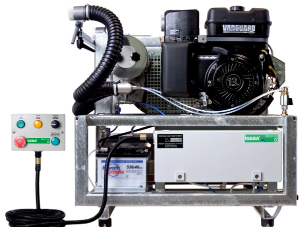
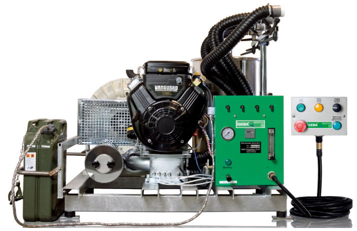
Source: own compilation, JKI

Table 38: The models Maxi-Pro 2D, Maxi-Pro 4 and Typhoon 1 by Curtis Dyna-Fog.

Model	Curtis Dyna-Fog Maxi-Pro 2D	Curtis Dyna-Fog Maxi-Pro 4	Curtis Dyna-Fog Typhoon 1
			
Power (HP)	18	18	9.5
Number of nozzle	2	4	1
Droplet spectrum (µm)	$D_{v0.9}$ < 20	$D_{v0.9}$ < 20	$D_{v0.9}$ < 20
Flow rate (L h^{-1})		0-36	0-36
Formulation tank (L)	57	57	57
Flush tank (L)	3.8	3.8	3.8
Fuel tank (L)	74	7	7
Weight (kg)	135		135
Dimension (cm)	112 x 94 x 127	112 x 84 x 81	105 x 74 x 81
Reference	Curtis Dyna-Fog (2016c)	Curtis Dyna-Fog (2016c)	Curtis Dyna-Fog (2020)

Source: own compilation, JKI

Table 39: The models U 5 M, U 15 HD-M and U 40 HD-M by iGEBA.

Model	iGEBA U 5 M	iGEBA U 15 HD-M	iGEBA U 40 HD-M
			
Power (HP)	3.5	13	18
Number of nozzle	1	2	4
Droplet spectrum (µm)	VMD < 25	VMD < 15	VMD < 15
Flow rate (L h^{-1})	10	20	40
Formulation tank (L)	20	60	75
Flush tank (L)			
Fuel tank (L)	2	6	10
Weight (kg)	38	166	196
Dimension (cm)	60 x 53,5 x 58	87 x 79 x 91	110 x 95 x 68
Reference	iGEBA (2015c)	iGEBA (2015c)	iGEBA (2015c)

Source: own compilation, JKI

Table 40: The models 190 G4, 55 ES and 95 G4 of the Guardian-Linie by ADAPCO.

Model	ADAPCO 55 ES	ADAPCO 95 G4	ADAPCO 190 G4
			
Power (HP)	5.5	9.5	19
Number of nozzle	1	1	1
Droplet spectrum (µm)			
Flow rate (L h^{-1})			
Formulation tank (L)	9.46	56.7	56.7
Flush tank (L)		1.9	1.9
Fuel tank (L)	3.6	7	45.4
Weight (kg)	38.55	158.7	222.2
Dimension (cm)	86.8 x 39.7 x 43.1	95.9 x 75.6 x 68.6	119.4 x 101.6 x 75.9
Reference	ADAPCO (2023)	ADAPCO (2023)	ADAPCO (2023)

Source: own compilation, JKI

Table 41: The models LR 18, LR 18-2, LR 50, LR 4P and LR G by Longray.

Model	Longray LR 18	Longray LR 18-2	Longray LR 50	Longray LR 4P	Longray LR G
					
Power (HP)	18	18	Storage battery	7.6	7.6
Number of nozzle	1	2	1	4	4
Droplet spectrum (µm)	$D_{v0.9}$ < 20	$D_{v0.9}$ < 20	$D_{v0.9}$ < 50	$D_{v0.9}$ < 50	$D_{v0.9}$ < 50
Flow rate (L h^{-1})			0-50	0-50	0-50
Formulation tank (L)	60	60	70	60	60
Flush tank (L)	5	5	4		
Fuel tank (L)	36	36	--	16	16
Weight (kg)	190	190	186	200	200
Dimension (cm)	133 x 113 x 95	130 x 111 x 92	110 x 90 x 117	130 x 111 x 92	130 x 111 x 92
Reference	Longray (2013a)	Longray (2013a)	Longray (2013a)	Longray (2023a)	Longray (2023b)

Source: own compilation, JKI

Table 42: The models AU9000 und AU8115MS by MiCRON, Fontan Mobilstar by Swintec, TU100N by Vector Fog and tracFOG by pulsFOG.

Model	MiCRONAIR AU9000	MiCRONAIR AU8115MS	Fontan Mobilstar M	Vector Fog TU100N	pulsFOG tracFOG
					
Power (HP)	10	13	16	7	15
Number of nozzle	2	1	2	3	2
Droplet spectrum (µm)	20-25	40-100	VMD < 30		20-30
Flow rate (L h^{-1})	0-84	12-210	5-50		60-120
Formulation tank (L)	50	100	69	130	400
Flush tank (L)	10	10	5		
Fuel tank (L)	3.3	5	20	5	
Weight (kg)	140	130	135	90	250
Dimension (cm)	88 x 85 x 70	140 x 76 x 85	87 x 75 x 95	111 x 72 x 76	105 x 78 x 170
Reference	Micron Group (2023c)	Micron Group (2023b)	Swingtec (2019a)	Vector Fog (2020)	pulsFOG (2010j)

Source: own compilation, JKI

Table 43: The models ULV 1200, ULV 1200 Twin, ULV 1200 (2 Nozzle) and ULV 1200 Twin (4 Nozzle) by White Fog.

Model	White Fog ULV 1200	White Fog ULV 1200 Twin	White Fog ULV 1200 (2 Nozzle)	White Fog ULV 1200 Twin (4 Nozzle)
				
Power (HP)	18	18	18	18
Number of nozzle	4	2	2	4
Droplet spectrum (µm)	10-30	10-30	10-30	10-30
Flow rate (L h^{-1})	0-31.8	0-31.8	0-31.8	0-31.8
Formulation tank (L)	60	100	60	100
Flush tank (L)	5	5	5	5
Fuel tank (L)	22	22	22	22
Weight (kg)	200	240	200	240
Dimension (cm)	110 x 99 x 85	120 x 99 x 85	110 x 99 x 85	120 x 99 x 85
Reference	White Fog (2020h)	White Fog (2020i)	White Fog (2020g)	White Fog (2020j)

Source: own compilation, JKI

Table 44: The models ULV 1400, ULV 2000, ULV 900, ULV 900 (2 Nozzle) and ULV 900 Twin by White Fog.

Modell	White Fog ULV 1400	White Fog ULV 2000	White Fog ULV 900	White Fog ULV 900 (2 Nozzle)	White Fog ULV 900 Twin
					
Power (HP)	18	18	13	13	13
Number of nozzle	4	4	4	2	4
Droplet spectrum (µm)	10-30	10-30	10-30	10-30	10-30
Flow rate (L h^{-1})	0-31.8	0-31.8	0-31.8	0-31.8	0-31.8
Formulation tank (L)	60	100	60	60	100
Flush tank (L)	5	10	5	5	5
Fuel tank (L)	22	40	6.1	6.1	6.1
Weight (kg)	200	360	150	150	200
Dimension (cm)	100 x 85 x 108	100 x 85 x 108	110 x 99 x 85	110 x 99 x 85	120 x 99 x 85
Reference	White Fog (2020k)	White Fog (2020l)	White Fog (2020d)	White Fog (2020e)	(White Fog 2020f)

Source: own compilation, JKI

6.4.4 Portable Thermal Fogging Devices

Hand-carried thermal fogging devices are primarily used for spray treatments indoors, in buildings, and outdoors to treat areas inaccessible by vehicles, with a VMD of less than 30 µm. It features a thermal energy nozzle into which the insecticide (both oil- and water-based formulations) is metered.

There are also portable thermal misting devices, known as pulse misting devices with a special design, allowing for the application of water-based mist. These devices have an open pneumatic nozzle system with both kinetic and thermal energy sources (impulse combustion chamber without rotating parts), generating the necessary pneumatic pressure to atomize the mist into droplets of the desired size.

Furthermore, manually carried thermal fogging devices must be equipped with a small hand- or battery-operated air pump to pressurize the fuel line when starting the machine, unless the fuel injection system is not pressurized. It should have a handle for easy and secure carrying and a sturdy frame to hold the various components. All hot surfaces must be adequately shielded to prevent operator burns during and immediately after operation. All parts regulated during device operation must be durably and visibly labeled. The spraying device must be equipped with clearly visible safety warnings cautioning the operator not to leave the device unattended during operation.

In addition, pulse jet devices must have a steel resonator capable of withstanding up to 1050°C. The misting device can be equipped with a fixed or removable tank, with the capacity clearly indicated. The filling opening must be at the top of the tank when the tank is securely attached to the unit. And a filter funnel must be present to facilitate filling when the opening is <90 mm. The fuel tank capacity must allow the operator to continuously empty a full formulation container with the recommended minimum flow rate without refilling the fuel tank. The fuel and formulation tanks should not be refilled while the device is hot. The fuel type must be indicated on the device. The regulation of liquid flow to the nozzle must be accomplished through a fixed but replaceable throttle or by a control valve. The flow rate for each throttle or control valve setting must be marked on the machine or specified in the operating manual. The VMD must be <30 µm at the recommended standard formulation performance for oil and/or water-based formulations. A thermal misting device designed for water-based larvicide sprays must have a separate opening/device for selecting larger droplet sizes up to 100 µm.

Table 45: The models Superhawk II, Trailblazer Electric Start, Patriot, Golden Eagle Electric Start XL and Mister III by Curtis Dyna-Fog.

Model	Curtis Dyna-Fog Superhawk II	Curtis Dyna-Fog Trailblazer Electric Start	Curtis Dyna-Fog Patriot	Curtis Dyna-Fog Golden Eagle Electric Start XL	Curtis Dyna-Fog Mister III
					
Power (HP)	30	30	30	30	44
Droplet spectrum (µm)	0.5-50	0.5-50	0.5-50	0.5-50	
Flow rate (L h^{-1})	0-42	0-19	0-19	0-34	0-45.4
Formulation tank (L)	4.5	3.8	3.8	4.2	11.4
Fuel tank (L)	1	0.8	0.8	1	3.78
Weight (kg)	7.5	12.5	12.5	8.6	17.7
Dimension (cm)	132 x 24 x 36	74 x 25.4 x 46.4	74 x 25.4 x 46.4	132 x 24.1 x 36.8	
Reference	Curtis Dyna-Fog (2016d)	Curtis Dyna-Fog (2016f)	Curtis Dyna-Fog (2016f)	Curtis Dyna-Fog (2016b)	Curtis Dyna-Fog (2016e)

Source: own compilation, JKI

Table 46: The models TF 34, TV 35 and EVO 35 by iGEBA.

Model	iGEBA TF 34	iGEBA TF 35	iGEBA EVO 35
			
Power (HP)	13.6	25.4	25.4
Droplet spectrum (µm)	$D_{v0.9} < 20$		
Flow rate (L h^{-1})	6	42	42
Formulation tank (L)	5.7	5.7	6.5
Fuel tank (L)	1.2	1.2	1.2
Weight (kg)	6.6	7.9	7.8
Dimension (cm)	78 x 27 x 34	137.5 x 27 x 34	133.5 x 28.5 x 34
Reference	iGEBA (2015a)	iGEBA (2015b)	iGEBA (2014a)

Source: own compilation, JKI

Table 47: The models TS 35A, TS 35A[E], TS 75L and TS 36S by Longray.

Model	Longray TS 35A	Longray TS 35A[E]	Longray TS 75L	Longray TS 36S
				
Power (HP)	25.2	25.2	25.2	25.2
Droplet spectrum (µm)				
Flow rate (L h^{-1})	42	42	80	42
Formulation tank (L)	6	6	6	6
Fuel tank (L)	2	2	2	2
Weight (kg)	7.9	7.9	9.5	9.1
Dimension (cm)	137 x 27 x 31	137 x 27 x 31	130 x 29 x 36	138 x 29 x 36
Reference	Longray (2013a)	Longray (2013a)	Longray (2013a)	Longray (2013a)

Source: own compilation, JKI

Table 48: The models 35ES, 35EP, 9ES and 9EP by Micron Groupe.

Model	MiCRONAIR 35ES	MiCRONAIR 35EP	MiCRONAIR 9ES	MiCRONAIR 9EP
				
Power (HP)	25	25	15	16
Droplet spectrum (µm)				
Flow rate ($L\ h^{-1}$)	8-42	8-42	8-42	8-43
Formulation tank (L)	6	6	6	6
Fuel tank (L)	1.2	1.2	1.2	1.2
Weight (kg)	8.3	7.8	7.6	7.1
Dimension (cm)	136 x 27 x 34	136 x 27 x 34	114 x 27 x 34	115 x 27 x 34
Reference	Micron Group (2023h)	Micron Group (2023h)	Micron Group (2023h)	Micron Group (2023h)

Source: own compilation, JKI

Table 49: The models SN 50, SN 50 PE, SN 50-10 and SN 50-10 PE by Swingtec

Model	Swingfog SN 50	Swingfog SN 50 PE	Swingfog SN 50-10	Swingfog SN 50-10 PE
			 Spraying tank, stainless steel, capacity 9 l, Swingfog SN 50-10	 Spraying tank, polyethylene, capacity 10 l, Swingfog SN 50-10 PE
Power (HP)	25.4	25.4	25.4	25.4
Droplet spectrum (µm)	VMD < 30	VMD < 30	VMD < 30	VMD < 30
Flow rate (L h^{-1})	10-42	10-42	10-42	10-42
Formulation tank (L)	6.5	7	9	10
Fuel tank (L)	1.4	1.4	1.4	1.4
Weight (kg)	8.75	8.7	9.1	9
Dimension (cm)	133 x 29 x 33	133 x 29 x 33	133 x 34 x 33	133 x 34 x 33
Reference	Swingtec (2019c)	Swingtec (2019c)	Swingtec (2019c)	Swingtec (2019c)

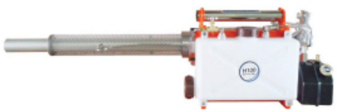
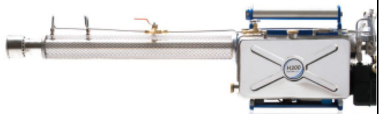
Source: own compilation, JKI

Table 50: The models SN 81, SN 81 PE, SN 81-20 PE and SN 81 Pump by Swingtec.

Model	Swingfog SN 81	Swingfog SN 81 PE	Swingfog SN 81-20 PE	Swingfog SN 81 Pump
		 Spraying tank: SN 81, stainless steel, 9 l SN 81 PE, polyethylene, 10 l		
Power (HP)	50.8	50.8	50.8	50.8
Droplet spectrum (µm)	VMD < 30	VMD < 30	VMD < 30	VMD < 30
Flow rate (L h^{-1})	23-62	23-62	23-62	23-62
Formulation tank (L)	9	10	20	separate
Fuel tank (L)	4.5	4.5	4.5	4.5
Weight (kg)	14.6	14.5	16.4	21.2
Dimension (cm)	173 x 39 x 33	173 x 39 x 33	173 x 39 x 33	172 x 50 x 50
Reference	Swingtec (2019d)	Swingtec (2019d)	Swingtec (2019d)	Swingtec (2019d)

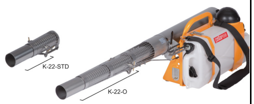
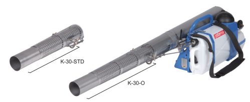
Source: own compilation, JKI

Table 51: The models H100, H100 SF, H200 SF and H200 SF-SS by Vector Fog.

Model	Vector Fog H100	Vector Fog H100 SF	Vector Fog H200 SF	Vector Fog H200 SF-SS
				
Power (HP)	25.5	25.5	25.5	25.5
Droplet spectrum (µm)	5.0-30	5.0-30	5.0-30	5.0-30
Flow rate (L h^{-1})	30	30	40	40
Formulation tank (L)	4.5	4.5	6.5	6.5
Fuel tank (L)	1.2	1.2	1.2	1.2
Weight (kg)	8.5	8.5	10.8	10.8
Dimension (cm)	115 x 34 x 25	115 x 34 x 25	133 x 28 x 38	133 x 28 x 38
Reference	Vector Fog (2020)	Vector Fog (2020)	Vector Fog (2020)	Vector Fog (2020)

Source: own compilation, JKI

Table 52: The models K-10-SP, K-10-Desert, K-22-STD/K-22-O, K-22-Bio, K-30-STD/K-30-O and K-30-Bio by pulsFOG.

Model	pulsFOG K-10-SP	pulsFOG K-10-Desert	pulsFOG K-22-STD/K-22-O	pulsFOG K-22-Bio	pulsFOG K-30-STD/K-30-O	pulsFOG K-30-Bio
						
Power (HP)	24.1	24.1	50.8	50.8	101.6	101.6
Droplet spectrum (µm)	< 150	< 150	< 150	< 150	< 100	< 100
Flow rate (L h^{-1})	10-35	10-35	20-60	20-60	30-120	30-120
Formulation tank (L)	5	6	9	2 x 5	9	6 + 5
Fuel tank (L)	2	2	2	2	2	2
Weight (kg)	7	8.5	10.5	11	13.5	14.5
Dimension (cm)	106 x 29 x 33	106 x 29 x 33	132 x 33 x 36	132 x 33 x 36	149 x 36 x 35	149 x 36 x 35
Reference	pulsFOG (2010a)	pulsFOG (2018a)	pulsFOG (2010d)	pulsFOG (2018b)	pulsFOG (2010i)	pulsFOG (2017a)

Source: own compilation, JKI

6.4.5 Vehicle-Mounted Thermal Fogging Devices

Vehicle-mounted thermal (pulse jet) fogging devices are aerosol-generating machines that can be mounted on a flatbed truck or trailer, a boat, an amphibious vehicle, or a drone. These devices are typically used for treating outdoor surfaces and leave no spray residues. Additionally, the various components must be mounted on a corrosion-resistant frame that fits an appropriate vehicle.

Furthermore, there must be a formulation tank and an additional flushing tank present, allowing the pesticide to be flushed from the system when wettable powders are used, or a pump system with a reverse function that enables automatic suction of any remaining fluid in the lines. The device must be equipped with a suitable control system operable from the vehicle cabin. A fuel tank must be present, with a capacity sufficient for operating the spraying device, allowing a full formulation tank to be emptied during the spraying process. All individual tanks must be durably and visibly labeled and equipped with a drain device. The motor exhaust and movable parts must be shielded to prevent injuries.

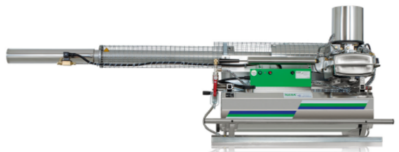
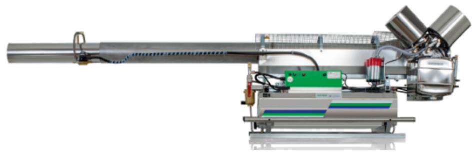
Moreover, the formulation tank capacity must be at least 50 liters, and a filter funnel must be provided to facilitate spill-free filling when the tank opening is less than 90 mm wide. The fuel type must be clearly indicated on the filling cap. The misting device should feature a manual flow control that can be operated in a fixed setting. A shut-off valve must automatically close when a part of the device is turned off or stops functioning. The misting device nozzle must release droplets with a VMD of no more than 30 µm in space sprayers. The remote control panel in the vehicle cabin must be equipped with permanently labeled switches for independent machine and pesticide on/off control.

Table 53: The models F500 by London Fogger and Blackhawk Pro and 1200 by Curtis Dyna-Fog.

Model	London Fogger F500	Curtis Dyna-Fog Blackhawk-Pro	Curtis Dyna-Fog 1200
			
Power (HP)	19	51	9.5
Droplet spectrum (µm)	0.5-30		10-100
Flow rate (L h^{-1})	135	75	456
Formulation tank (L)	208	50	56.8
Fuel tank (L)	11.36	4.5	4.7
Weight (kg)	100	18.6	281
Dimension (cm)	76 x 84 x 61	173.5 x 38.1 x 42.7	79 x 35 x 32
Reference	London Foggers (2022d)	Curtis Dyna-Fog (2014)	Curtis Dyna-Fog (2016a)

Source: own compilation, JKI

Table 54: The models TF 65/20 E, TF 95 HD and TF 160 HD by iGEBA.

Model	iGEBA TF 65/20 E	iGEBA TF 95 HD	iGEBA TF 160 HD
			
Power (HP)	50	50	112
Droplet spectrum (µm)			
Flow rate (L h^{-1})	20	60	60
Formulation tank (L)	5.5	5.5	10
Fuel tank (L)	17.7	39.5	65
Weight (kg)	184 x 45 x 51	198 x 62 x 58	262 x 62 x 70
Dimension (cm)	iGEBA (2014b)	iGEBA (2014b)	iGEBA (2014b)

Source: own compilation, JKI

Table 55: The models TS 95 by Longray and SN 101 E, SN 101 M and SN 101 Pump by Swingtec.

Model	Longray TS 95	Swingfog SN 101 E	Swingfog SN 101 M	Swingfog SN 101 Pump
				
Power (HP)	50	57.3	57.3	57.3
Droplet spectrum (µm)		VMD < 30	VMD < 30	VMD < 30
Flow rate (L h^{-1})	60	69	69	separate
Formulation tank (L)	5	5.6	5.6	21.3
Fuel tank (L)	47	41	39.6	39
Weight (kg)	200 x 60 x 75	177 x 58 x 56	177 x 63 x 55	177 x 56 x 50
Dimension (cm)	Longray (2013b)	Swingtec (2019e)	Swingtec (2019e)	Swingtec (2019e)

Source: own compilation, JKI

Table 56: The models H300 SF, H400 SF and H500 SF by Vector Fog.

Model	Vector Fog H300 SF	Vector Fog H400 SF	Vector Fog H500 SF
			
Power (HP)	28.2	30.8	61.7
Droplet spectrum (µm)	5.0-30	5.0-30	5.0-30
Flow rate (L h^{-1})	13.5	23	150
Formulation tank (L)	2.4	3.2	15
Fuel tank (L)	20	36	120
Weight (kg)		165 x 110 x 58	165 x 72 x 80
Dimension (cm)	Vector Fog (2020)	Vector Fog (2020)	Vector Fog (2020)

Source: own compilation, JKI

Table 57: The models K-22-10-STD, K-22-20-STD, K-22-20-Bio and K-50 by pulsFOG.

Model	pulsFOG K-22-10-STD	pulsFOG K-22-20-STD	pulsFOG K-22-20-Bio	pulsFOG K-50
				
Power (HP)	50.8	50.8	50.8	171
Droplet spectrum (µm)	< 150	< 150	< 150	< 150
Flow rate (L h^{-1})	55	55	2 x 55	2 x 55
Formulation tank (L)	20	20	20	2 x 20
Fuel tank (L)	18	18	42	55
Weight (kg)	132 x 38 x 47	132 x 38 x 47	138 x 87 x 58	185 x 86 x 61
Dimension (cm)	pulsFOG (2010b)	pulsFOG (2010b)	pulsFOG (2010c)	pulsFOG (2017b)

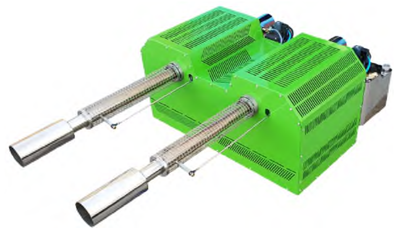
Source: own compilation, JKI

Table 58: The models K-30-20-STD (small), K-30-20-STD (large), K-30-20-Bio (small), K-30-20-Bio (large) and K-30-20-Bio (large two) by pulsFOG.

Model	pulsFOG K-30-20-STD (small)	pulsFOG K-30-20-STD (large)	pulsFOG K-30-20-Bio (small)	pulsFOG K-30-20-Bio (large)	pulsFOG K-30-20-Bio (large two)
					
Power (HP)	101.6	101.6	101.6	101.6	101.6
Droplet spectrum (µm)	< 150	< 150	< 150	< 150	< 150
Flow rate (L h^{-1})	55	80	2 x 55	2 x 55	2 x 65
Formulation tank (L)	20	20	20	20	20
Fuel tank (L)	22	55	22	45	70
Weight (kg)	151 x 41 x 49	151 x 87 x 50	151 x 42 x 49	160 x 97 x 77	160 x 97 x 94
Dimension (cm)	pulsFOG (2010h)	pulsFog (2012)	pulsFOG (2010g)	pulsFOG (2010f)	pulsFOG (2010e)

Source: own compilation, JKI

Table 59: The models SM 700, Ultra Fogger, SM 700 Dual and SM 900 by White Fog.

Model	White Fog SM 700	White Fog Ultra Fogger	White Fog SM 700 Dual	White Fog SM 900
				
Power (HP)	57.3	10	50.8	57.3
Droplet spectrum (µm)		10-100		
Flow rate (L h^{-1})	60	200	150	100
Formulation tank (L)	10	5.3	2 x 7	4.5
Fuel tank (L)	60	150	50	80
Weight (kg)	227 x 65 x 63	210 x 90	162 x 51 x 38	199 x 100 x 500
Dimension (cm)	White Fog (2020b)	White Fog (2022)	White Fog (2020a)	White Fog (2020c)

Source: own compilation, JKI

6.4.6 Aircraft and Helicopter Mounted Spraying Systems

Vector control, however, can occur not only from the ground but also from the air. Aerial spraying is a method recommended for the rapid control of adult mosquito populations during outbreaks or epidemics in large urban areas, especially where access with ground equipment is difficult and where large areas need to be treated quickly (WHO 2003; Carney et al. 2008; Bonds 2012; Ruktanonchai et al. 2014). For the application of cold fogging, both fixed-wing aircraft and helicopters are employed, equipped with rotary atomizers (Table 60) or high-pressure systems. A rotary atomizer consists of a cylindrical metal mesh driven at high speed by an electric motor or by fan blades set in motion by the forward speed of the aircraft. The pitch of the fan blades is adjustable, allowing the speed of the atomizer to be set based on the flight speed. In addition to the centrifugal force that generates droplets, the liquid is further broken down into smaller droplets by the air shear (WHO 2003).

Lothrop et al. (2008) utilized a single-engine fixed-wing aircraft equipped with two Mironair AU5000 atomizers (Micron Sprayers Ltd., Herefordshire, UK). The Mironair AU5000 atomizer is versatile and can be used for ULV and conventional applications. The VMD can be adjusted between 50 to 400 µm depending on the application (Micron Group 2022). Furthermore, Dzul-Manzanilla et al. (2019) employed a Cessna 206-H with 2 Mironair AU 4000 atomizers in Mexico, and Carney et al. (2008) used a fixed-wing aircraft with 2 Mironair AU 4000 atomizers in California with success in vector control.

Table 60: The models AU5000, AU4000 and AU6539 by Micron Groupe.

Model	MiCRONAIR AU5000	MiCRONAIR AU4000	MiCRONAIR AU6539
			
Flow rate (L min^{-1})	0-23	0-30	0-3
Droplet spectrum (µm)	VMD 50-400	VMD 30-400	VMD 45-120
Air speed (km h^{-1})	145-240	80-240	0-240
Weight (kg)	1.8	2.8	2
Reference	Micron Group (2022)	Micron Group (2023k)	Micron Group (2023l)

Source: own compilation, JKI

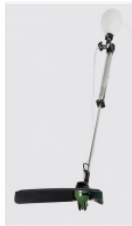
6.5 ULV Applications in Plant Protection

ULV applications play a relatively minor role in plant protection. According to §16 of the German Plant Protection Act (PflSchG), a device used for the application of plant protection agents must be designed in such a way that, when used properly and according to its intended purpose, the application of the plant protection agent has no harmful effects on the health of humans and animals, the groundwater, or any other unacceptable effects, particularly on the natural environment (BMJ 2012). Until 2012, device testing was mandatory for all manufacturers, and a range of devices capable of ULV applications was tested and approved by the JKI (JKI 2011). Since 2012, the recognition testing according to §52 of the PflSchG has become voluntary (JKI 2023).

Plant protection equipment intended for the market must indeed comply with the requirements of the Machinery Directive for the application of pesticides (Directive 2009/127/EC). However, manufacturers ensure compliance with these requirements themselves by affixing the CE certificate along with a declaration of conformity (BVL 2019). The JKI assists with the CE conformity declaration process and examines manufacturer documentation such as user manuals, description sheets, and technical information for completeness and plausibility. Furthermore, after successful document review, the device can be entered into the JKI's Descriptive List, confirming its usability under §16 PflSchG regardless of the manufacturer. For devices listed in the Descriptive List prior to 2012, recognitions expired and were not re-applied for by the manufacturers. Currently, the JKI database lists three fogging devices as recognized plant protection equipment: the K-10, K-22, and K-30 in the standard variant from pulsFOG Dr. Stahl Sohn GmbH. These three devices are recognized for plant protection measures in enclosed and sufficiently sealed spaces (greenhouses and stored goods protection) using approved plant protection agents with this application method (JKI 2016b; JKI 2016a; JKI 2022a). The absence of other ULV application devices in the list does not mean that there are no devices for this purpose in the market; rather, it reflects the lack of an overview due to voluntary testing, showing which devices are available for ULV applications in plant protection.

Literature and internet research revealed significant differences in the design and application areas of devices used for the application of biocides in vector control compared to devices for field application of plant protection agents. Vector control employs devices that generate very fine droplets, suspended in the air for an extended period to target as many vectors as possible. In contrast, plant protection devices are predominantly designed for herbicide application. These devices feature a rotary nozzle producing droplets within a very narrow spectrum and incorporate a spray shield or hood to minimize contamination of non-target surfaces and organisms. Table 61 through Table 66 present a compilation of devices available for plant protection based on internet research and information from respective datasheets referenced. No guarantee is provided for the completeness of devices present in the market, and this compilation does not imply any judgment. The listing aims solely to provide a comprehensive information resource.

Table 61: The models MiCron Herbi 4, Herbidome 350/600, Microfit Pro, Herbiflex 4 and Handy by Micron Groupe.

Model	MiCRON Herbi4	MiCRON Herbidome350/600	MiCRON MicrofitPro	MiCRON Herbiflex4	MiCRON Handy
					
Power	6V DC	6V DC	6V DC	6V DC	6V DC
Speed of the disc (rpm)	2000	1100	2800	2800	2000
Flow rate (mL min^{-1})	60-150	60-150	15-45	15-45	60-150
Number of nozzles	1	1	1	1	1
Formulation tank (L)	2.5, 5, 10	5, 10	5, 10	2.5, 5	5
Swath width (cm)	120	35-60	10-75	10-75	
Droplet spectrum (µm)	200-300	200-400	200	200	200-300
Weight (kg)	1.5	2.1	2.2	1.5	0.7
Reference	Micron Group (2023e)	Micron Group (2023f)	Micron Group (2023m)	Micron Group (2023g)	Micron Group (2023d)

Source: own compilation, JKI

Table 62: The models Pulmic Fenix, Pulmic Fenix 35, Pulmic Fenix Insect, Pulmic Fenix Pure and Pulmic Fenix Pure 35 by Grupo Sanz.

Model	Grupo Sanz Pulmic Fenix	Grupo Sanz Pulmic Fenix 35	Grupo Sanz Pulmic Fenix Insect	Grupo Sanz Pulmic Fenix Pure	Grupo Sanz Pulmic Fenix Pure 35
					
Power	3 V	3 V	3 V	3V	3 V
Speed of the disc (rpm)	4500	4500	6500-7000	4500	4500
Flow rate (mL min^{-1})	130-350	60	150	22-35	7-22
Number of nozzles	1	1	1	1	1
Formulation tank (L)	5, 10	5	1-10	1	1
Swath width (cm)		35	300		35
Droplet spectrum (µm)	250	250	50-80		
Weight (kg)	1	0.669	1.5	0.789	0.656
Reference	Grupo Sanz (2019a)	Grupo Sanz (2019b)	Grupo Sanz (2019c)	Grupo Sanz (2019d)	Grupo Sanz (2019e)

Source: own compilation, JKI

Table 63: The models Mankar HQ 30/45, Two 50/80/110 Flex, Two S 25/40/55 Flex, One S 25/40/55 Flex and One 45 by Mantis ULV

Model	Mankar HQ 30, HQ 45	Mankar Two 50 Flex, Two 80 Flex, Two 110 Flex	Mankar Two S 25 Flex, Two S 40 Flex, Two S 55 Flex	Mankar One S 25 Flex, One S 40 Flex, One S 55 Flex	Mankar One 45
					
Number of nozzles	1	2	2	1	1
Formulation tank (L)	1	1	1	1	1
Swath width (cm)	12-30, 15-45	30-50, 60-80, 70-110	2x15-25, 25-40, 40-55	15-25, 25-40, 40-55	45
Weight (kg)	2.6	24	24	22.5	22.5
Reference	Mantis ULV (2023)	Mantis ULV (2023)	Mantis ULV (2023)	Mantis ULV (2023)	Mantis ULV (2023)

Source: own compilation, JKI

Table 64: The Micromax, AU8120, Turbofan and X-1 atomisers for attaching and attaching devices by Micron Groupe.

Model	MiCron Micromax	MiCron AU8120	MiCron Turbofan	MiCron X-1
				
Speed of the disc (rpm)	2000-5000	2000-10000	4000-5000	8000-15000
Flow rate (mL min^{-1})	125-3000	20-2000	250-8000	50-100
Droplet spectrum (µm)	75-500	40-400	100-120	35-150
Application rate (L ha^{-1})	10-200			20-200
Weight (kg)	1	0.7	8.1	0.13
Length (cm)		15.5	35	
Diameter (cm)		22.5	45	
Reference	Micron Group (2023i)	Micron Group (2023j)	Micron Group (2023o)	Micron Group (2023r)

Source: own compilation, JKI

Table 65: The models Varimant Two-S 25/40/55 Flex, Varimant One-S 25/40/55 Flex, Two-E 50/80/110 Flex, Unima One-ES 25/40/55 Flex, Unima Two-P 50/80/110 Flex, 3 Flexomat Two 50/80/110 Flex and 2 Flexomat One 25/40/55 Flex by Mantis ULV.

Model	Varimant Two-S 25 Flex, Two-S 40 Flex, Two-S 55 Flex	Varimant One-S 25 Flex, One-S 40 Flex, One-S 55 Flex	Unima Two-E 50 Flex, Two-E 80 Flex, Two-E 110 Flex	Unima One-ES 25 Flex, One-ES 40 Flex, One-ES 55 Flex	Unima Two-P 50 Flex, Two-P 80 Flex, Two-P 110 Flex	Flexomat Two 50 Flex, Two 80 Flex, Two 110 Flex	Flexomat One 25 Flex, One 40 Flex, One 55 Flex
							
Number of nozzles	2	1	2	1	2	2	1
Formulation tank (L)	6	6	6	6	6	3	3
Spray width (cm)	2x15-25, 25-40, 40-55	15-25, 25-40, 40-55	30-50, 60-80, 70-110	15-25, 25-40, 40-55	30-50, 60-80, 70-110	30-50, 60-80, 70-110	15-25, 25-40, 40-55
Working width (cm)	100-150, 130-180, 160-210	75, 90, 105					
Weight (kg)	42, 45, 48	39, 41, 44	31, 34, 37	28, 31, 33	23, 25, 28		
Reference	Mantis ULV (2023)	Mantis ULV (2023)	Mantis ULV (2023)	Mantis ULV (2023)	Mantis ULV (2023)	Mantis ULV (2023)	Mantis ULV (2023)

Source: own compilation, JKI

Table 66: The models Undavina 250/400/600/900 CDA, Spraydome 400/600/1000/1200 CDA and Varidome 80/130 CDA by Micron Groupe.

Model	Undavina 250 CDA, 400 CDA, 600 CDA, 900 CDA	Spraydome 400 CDA, 600 CDA, 1000 CDA, 1200 CDA	Varidome 80 CDA, 130 CDA
			
Swath width (mm)	250, 400, 600, 900	400, 600, 1000, 1200	80-800, 130-800
Application rate (L ha^{-1})	20-80	20-80	20-50
Weight (kg)	15, 17, 18, 19	17, 18, 26, 36	
Reference	Micron Group (2023p)	Micron Group (2023n)	Micron Group (2023q)

Source: own compilation, JKI

6.6 Discussion and Conclusion

ULV (Ultra-Low Volume) application for vector control could gain significance in Germany in the coming years. The Asian tiger mosquito (*Aedes albopictus*) has invaded Germany and is among the carriers of the West Nile virus. In 2007, the first eggs of the non-native species *St. albopicta* were found at a rest area on a highway in southern Germany (Pluskota et al. 2008). By 2012, several adult Asian tiger mosquitoes were documented in the Upper Rhine Valley (Becker et al. 2012; Kampen et al. 2012; Werner et al. 2012). Established populations now exist in several districts in Baden-Württemberg (FLI 2022b). The action plans developed by the National Expert Commission "Mosquitoes as Disease Vectors" in 2016 and 2022 stipulates that, upon mosquito detection, monitoring should be the primary step to assess mosquito populations. Subsequent control measures are primarily limited to eliminating potential breeding sites (removing objects that collect rainwater) or treating potential breeding sites with *Bti* preparations (FLI 2016a; FLI 2022a). The use of insecticides against adult mosquito stages should only occur in the event of an epidemic, with local and limited application by trained pest controllers under official orders, as these agents lack specificity (UBA 2015; FLI 2016b). The presence of the Asian tiger mosquito alone is insufficient grounds for control measures. According to §17 of the Infection Protection Act, the spread of disease agents must be confirmed before competent authorities, usually health departments, can order control measures. If no disease agent is detected, it is at the discretion of affected districts to take necessary preventive actions (BMJ 2000; UBA 2015).

In the case of an epidemic requiring insecticide use for vector control, various manufacturers offer different devices (Table 31 to Table 60). These include portable and non-portable cold and thermal fogging devices. However, all devices operate on the same principle: the dispersion of extremely fine droplets that remain airborne for an extended time to combat flying vectors searching for food. This approach contradicts §16 of the Plant Protection Act. In plant protection, insects are not targeted while flying in search of food; rather, systemic agents are applied, which insects ingest during feeding, or contact agents are used, affecting insects on their host plants. To comply with §16 and account for this, plant protection employs devices and techniques generating larger droplets that swiftly fall onto target plants and minimize drift into non-target areas. Consequently, devices for vector control cannot be directly compared to those used in plant protection.

7 List of references

ADAPCO (2023): Guardian ULV - The Guardian line of ULV sprayers from ADAPCO. from https://azelisaes-us.com/wp-content/uploads/Guardian-ULV-Sprayers.pdf, 19.04.2023.

AFPMB (2019): Technical Guide No. 13 - Dispersal of Ultra Low Volume (ULV) Insecticides by Cold Aerosol and Thermal Fog Ground Application Equipment.

Al-Sarar, A. S.; Al-Shahrani, D.; Hussein, H. I.; Bayoumi, A. E.; Abobakr, Y. (2014): Evaluation of Cold and Thermal Fogging Spraying Methods for Mosquito Control. Neotrop Entomol. 43: 85-89, https://doi.org/10.1007/s13744-013-0180-y.

Ali, M. A.; Nasir, A.; Khan, F. H.; A., K. M. (2011): Fabrication of Ultra Low Volume (ULV) Pesticide Sprayer Test Bench Pakistan Journal of Agricultural Sciences. 48: 135-140.

Arro-Gun (2023): Bullet. from https://azelisaes-us.com/wp-content/uploads/BULLETspec1.pdf, 28.04.2023.

Arvidsson, T.; Bergström, L.; Kreuger, J. (2011): Spray drift as influenced by meteorological and technical factors. Pest Management Science. 67: 586-598, http://doi.org/10.1002/ps.2114.

ASABE (2020): ASABE S572: Spray Nozzle Classification by Droplet Spectra. Transactions of the ASABE.

Auguie, B. (2017): gridExtra: Miscellaneous Functions for "Grid" Graphics. from https://CRAN.R-project.org/package=gridExtra, 10.10.2023.

Awadhwal, N. K.; Cabrido, E. F.; Quick, G. R. (1991): Minimizing drift and exposure from knapsack sprayers. Journal of Environmental Science and Health, Part B. 26: 589-600, https://doi.org/10.1080/03601239109372758.

Bai, G.; Nakano, K.; Mizukami, T.; Miyahara, S.; Ohashi, S.; Kubota, Y.; Takizawa, K.-i.; Yan, H. (2013): Characteristics and classification of Japanese nozzles based on relative spray drift potential. Crop Protection. 46: 88-93, http://doi.org/10.1016/j.cropro.2012.12.017.

Bateman, R. P.; Matthews, G. A.; Hall, F. R. (2007): Ground-based application equipment. In: L. A. Lacey and H. K. Kaya eds. Field Manual of Techniques in Invertebrate Pathology: Application and Evaluation of Pathogens for Control of Insects and other Invertebrate Pests. 73-98. Springer Netherlands, Dordrecht.

BAuA (2017): Anwendungsbestimmungen für das Biozid-Produkt Dipel ES (Application conditions for the biocidal product Dipel ES). from https://www.baua.de/SiteGlobals/Layout/DataViews/Datarecord_DBTool-Helper-BlobJSP-Biozide.html?view=renderDatarecordBlob&blobId=318, 13.02.2017.

BBA (2002): Test Report of the BBA for Flatfan nozzle AIRMIX 110 05. from https://psmvt6.julius-kuehn.de/anwendung/PDFs/G1638Bericht_e.pdf, 05.10.2018.

Becker, N.; Geier, M.; Balczun, C.; Bradersen, U.; Huber, K.; Kiel, E.; Krueger, A.; Lühken, R.; Orendt, C.; Plenge-Boenig, A.; Rose, A.; Schaub, G.; Tannich, E. (2012): Repeated introduction of Aedes albopictus into Germany, July to October 2012. Parasitology research, https://doi.org/10.1007/s00436-012-3230-1.

BMELV (2010): Gute fachliche Praxis im Pflanzenschutz - Grundsätze für die Durchführung (Good professional practice in crop protection - principles for implementation). from https://www.bmel.de/SharedDocs/Downloads/Broschueren/GutePraxisPflanzenschutz.pdf?__blob=publicationFile, 20.04.2020.

BMJ (2000): Gesetz zur Verhütung und Bekämpfung von Infektionskrankheiten beim Menschen (Infektionsschutzgesetz - IfSG). from https://www.gesetze-im-internet.de/ifsg/IfSG.pdf, 22.03.2022.

BMJ (2012): Gesetz zum Schutz der Kulturpflanzen (Law for the protection of crops). from https://www.gesetze-im-internet.de/pflschg_2012/PflSchG.pdf, 30.10.2018.

Bonds, J. A. S. (2012): Ultra-low-volume space sprays in mosquito control: a critical review. Medical and Veterinary Entomology. 26: 121-130, https://doi.org/10.1111/j.1365-2915.2011.00992.x.

Boubidi, S. C.; Roiz, D.; Rossignol, M.; Chandre, F.; Benoit, R.; Raselli, M.; Tizon, C.; Cadiou, B.; Tounsi, R.; Lagneau, C.; Fontenille, D.; Reiter, P. (2016): Efficacy of ULV and thermal aerosols of deltamethrin for control of Aedes albopictus in nice, France. Parasit Vectors. 9: 597, http://doi.org/10.1186/s13071-016-1881-y.

Britch, S. C.; Linthicum, K. J.; Walker, T. W.; Farooq, M.; Gordon, S. W.; Clark, J. W.; Ngere, F.; Ngonga, D.; Chepchieng, C. (2011): Evaluation of ULV applications against Old World sand fly (Diptera: Psychodidae) species in equatorial Kenya. Journal of Medical Entomology. 48: 1145-1159, https://doi.org/10.1603/me11025.

Britch, S. C.; Linthicum, K. J.; Wynn, W. W.; Walker, T. W.; Farooq, M.; Smith, V. L.; Robinson, C. A.; Lothrop, B. B.; Snelling, M.; Gutierrez, A.; Lothrop, H. D.; Kerce, J. D.; Becnel, J. J.; Bernier, U. R.; Pridgeon, J. W. (2010): Evaluation of ULV and thermal fog mosquito control applications in temperate and desert environments. Journal of the American Mosquito Control Association. 26: 183-197, https://doi.org/10.2987/09-5948.1.

Butler Ellis, M. C.; Alanis, R.; Lane, A. G.; Tuck, C. R.; Nuyttens, D.; van de Zande, J. C. (2017): Wind tunnel measurements and model predictions for estimating spray drift reduction under field conditions. Biosystems Engineering. 154: 25-34, http://doi.org/10.1016/j.biosystemseng.2016.08.013.

BVL (2019): Modul 9: Anwendungstechnik. from https://www.bvl.bund.de/SharedDocs/Downloads/04_Pflanzenschutzmittel/10_Folienserie_Naturhaushalt/psm_Folienserie_Naturhaushalt_Modul9_Anwendungstechnik-LADEN.pptx?__blob=publicationFile&v=5, 22.03.2023.

Carlsen, S. C. K.; Spliid, N. H.; Svensmark, B. (2006): Drift of 10 herbicides after tractor spray application. 2. Primary drift (droplet drift). Chemosphere. 64: 778-786, https://doi.org/10.1016/j.chemosphere.2005.10.060.

Carney, R. M.; Husted, S.; Jean, C.; Glaser, C.; Kramer, V. (2008): Efficacy of aerial spraying of mosquito adulticide in reducing incidence of West Nile Virus, California, 2005. Emerg Infect Dis. 14: 747-754, http://doi.org/10.3201/eid1405.071347.

Chadee, D. D. (1988): Landing periodicity of the mosquito Aedes aegypti in Trinidad in relation to the timing of insecticidal space-spraying. Medical and Veterinary Entomology. 2: 189-192, https://doi.org/10.1111/j.1365-2915.1988.tb00071.x.

Clarke (2022): COUGAR ULV SPRAYER - GRIZZLY® ULV SPRAYER - PRO-MIST® DURA ELECTRIC ULV SPRAYER. from https://www.clarke.com/wp-content/uploads/2022/03/Cougar_2019.pdf, 05.05.2023.

Clarke (2023): 1800E ULV Sprayer. from https://www.clarke.com/product/leco-1800e-ohv-ulv-sprayer/, 13.04.2023.

Craig, I. P.; Hewitt, A.; Terry, H. (2014): Rotary atomiser design requirements for optimum pesticide application efficiency. Crop Protection. 66: 34-39, https://doi.org/10.1016/j.cropro.2014.08.012.

Curtis Dyna-Fog (2014): Dyna-Fog Blackhawk-Pro. from http://www.dynafog.com/wp-content/uploads/2021/01/21-PEL-0085-Blackhawk-Pro-Spec-Sheet.pdf, 14.04.2023.

Curtis Dyna-Fog (2016a): Dyna-Fog Model 1200. from http://www.dynafog.com/wp-content/uploads/2016/03/Dyna-Fog-Model-1200-PDS.pdf, 14.04.2023.

Curtis Dyna-Fog (2016b): Golden Eagle Electric Start XL. from http://www.dynafog.com/wp-content/uploads/2016/03/Golden-Eagle-Electric-Start-XL-PDS.pdf, 17.04.2023.

Curtis Dyna-Fog (2016c): MAXI-PRO 2D and MAXI-PRO 4. from http://www.dynafog.com/wp-content/uploads/2015/07/MAXI-PRO-2D-AND-MAXI-PRO-4-PDS-1.pdf, 14.04.2023.

Curtis Dyna-Fog (2016d): Superhawk II. from http://www.dynafog.com/wp-content/uploads/2016/03/Superhawk-II-PDS.pdf, 17.04.2023.

Curtis Dyna-Fog (2016e): TORNADO and MISTER III. from http://www.dynafog.com/wp-content/uploads/2016/03/TORNADO-and-MISTER-III-PDS.pdf, 17.04.2023.

Curtis Dyna-Fog (2016f): Trailblazer and Patriot. from http://www.dynafog.com/wp-content/uploads/2016/03/Trailblazer-and-Patriot-PDS.pdf, 17.04.2023.

Curtis Dyna-Fog (2016g): Twister XL3. from http://www.dynafog.com/wp-content/uploads/2016/03/Twister-XL3-PDS.pdf, 14.04.2023.

Curtis Dyna-Fog (2020): Typhoon 1. from http://www.dynafog.com/wp-content/uploads/2020/03/Typhoon-1-Product-Data-Sheet-02_20.pdf, 14.04.2023.

Czaczyk, Z.; Kruger, G.; Hewitt, A. (2012): Droplet size classification of air induction flat fan nozzles. Journal of Protection Research. 52: 415-420.

Day, J. F.; Curtis, G. A. (1994): When It Rains, They Soar—and That Makes *Culex Nigripalpus* a Dangerous Mosquito. American Entomologist. 40: 162-167, http://doi.org/10.1093/ae/40.3.162.

de Mendiburu, F. (2021): agricolae: Statistical Procedures for Agricultural Research. from https://CRAN.R-project.org/package=agricolae, 16.06.2023.

de Rudnicki, V.; Douzals, J. P.; Tolosa, M.; Sidos, N.; Cotteux, E. (2012): Spraying quality assessment of sprayers devoted to mosquito control. In: CIGR-Ageng 2012, International Conference on Agricultural Engineering, Valencia, Spain.

de Ruiter, H.; Holterman, H. J.; Kempenaar, C.; Mol, H. G. J.; de Vlieger, J. J.; van de Zande, J. C. (2003): Influence of agricultural adjuvants and formulations on the emissionof pesticides to the atmosphere. Plant Research International, Wageningen UR-PRI. Report 59.

de Snoo, G. R.; de Wit, P. J. (1993): Pesticide drift from knapsack sprayers to ditches and ditch banks. Brighton Crop Protection. 2: 879-884.

de Snoo, G. R.; de Wit, P. J. (1998): Buffer Zones for Reducing Pesticide Drift to Ditches and Risks to Aquatic Organisms. Ecotoxicology and Environmental Safety. 41: 112-118, https://doi.org/10.1006/eesa.1998.1678.

DIN (2008): DIN 32645:2008-11 Chemische Analytik - Nachweis-, Erfassungs- und Bestimmungsgrenze unter Wiederholbedingungen - Begriffe, Verfahren, Auswertung (Chemical analysis - Decision limit, detection limit and determination limit under repeatability conditions - Terms, methods, evaluation). Deutsches Institut für Normung. . Beuth, Berlin.

Dokhan, M. R.; Kenawy, M. A.; Shaibi, T.; Annajar, B. B. (2017): Field Evaluation of Outdoor Ultra-Low Volume (ULV) Applications against Phlebotomine Sand Flies (Diptera: Psychodidae) in Al Rabta, North-West of Libya. Iranian Journal of Arthropod-Borne Diseases 11: 393-402.

Donkersley, P.; Nuyttens, D. (2011): A meta analysis of spray drift sampling. Crop Protection. 30: 931-936, https://doi.org/10.1016/j.cropro.2011.03.020.

Doruchowski, G.; Świechowski, W.; Masny, S.; Maciesiak, A.; Tartanus, M.; Bryk, H.; Hołownicki, R. (2017): Low-drift nozzles vs. standard nozzles for pesticide application in the biological efficacy trials of pesticides in apple pest and disease control. Science of The Total Environment. 575: 1239-1246, https://doi.org/10.1016/j.scitotenv.2016.09.200.

Dzul-Manzanilla, F.; Correa-Morales, F.; Medina-Barreiro, A.; Bibiano-Marín, W.; Vadillo-Sanchez, J.; Riestra-Morales, M.; del Castillo-Centeno, L. F.; Morales-Rios, E.; Martin-Park, A.; Gonzalez-Olvera, G.; Elizondo-Quiroga, A. E.; Lenhart, A.; Vazquez-Prokopec, G.; Che-Mendoza, A.; Manrique-Saide, P. (2019): Field Efficacy

Trials of Aerial Ultra-Low-Volume Application of Insecticides Against Caged Aedes aegypti in Mexico. Journal of the American Mosquito Control Association. 35: 140-146, https://doi.org/10.2987/18-6796.1.

Elliott, J. G.; Wilson, B. J. (1983): The Influence of weather on the efficiency and safety of pesticide application : the drift of herbicides : report of a working party of the Research and Development Committee, the British Crop Protection Council. The Council ; Exclusive distributor, ISBS, Croydon, England; Beaverton, Or.

EPA (1998): Product Performance Test Guidelines - OPPTS 810.1000 Overview, Definitions, and General Considerations. EPA 712–C–98–001.

EU (2009): Directive 2009/127/EC of the european parliament and of the council of 21 October 2009 amending Directive 2006/42/EC with regard to machinery for pesticide application. Official Journal of the European Union. L 310/29.

EU (2012): Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products. Official Journal of the European Union. L 167.

Farajollahi, A.; Healy, S. P.; Unlu, I.; Gaugler, R.; Fonseca, D. M. (2012): Effectiveness of Ultra-Low Volume Nighttime Applications of an Adulticide against Diurnal Aedes albopictus, a Critical Vector of Dengue and Chikungunya Viruses. PLOS ONE. 7: e49181, http://doi.org/10.1371/journal.pone.0049181.

Ferguson, J. C.; Gaussoin, R. E.; Eastin, J. A.; Sousek, M. D.; Kruger, G. R. (2016): Comparison of an ultra-low volume (ULV) sprayer against a conventional sprayer, for foliar fertiliser and fungicide applications in turfgrass. Journal of Plant Protection Research. 56: 54-59, https://doi.org/10.1515/jppr-2016-0008.

FLI (2016a): Aedes albopictus in Deutschland - Aktionsplan für den Umgang mit der Asiatischen Tigermücke. from https://www.openagrar.de/servlets/MCRFileNodeServlet/Document_derivate_00015127/Handlungsempfehlung_Aktionsplan-Ae-albopictus_22-07-2016.pdf, 22.03.2022.

FLI (2016b): Aedes albopictus in Deutschland - Handlungsbedarf und - optionen im Umgang mit der Asiatischen Tigermücke. from https://www.openagrar.de/servlets/MCRFileNodeServlet/Document_derivate_00015125/Handlungsempfehlung_Konzeptpapier_Ae-albopictus_19-04-2016_V2.pdf, 22.03.2022.

FLI (2022a): Integriertes Management von vektorkompetenten Stechmücken in Deutschland unter Berücksichtigung der Anwendung von Adultiziden. from https://www.openagrar.de/servlets/MCRFileNodeServlet/openagrar_derivate_00049699/Handlungsempfehlung_Management_inkl_Anwendung_Adultizide_08-11-2022_bf.pdf, 08.11.2023.

FLI (2022b): Nationale Expertenkommission „Stechmücken als Überträger von Krankheitserregern". from https://www.fli.de/de/kommissionen/nationale-expertenkommission-stechmuecken-als-uebertraeger-von-krankheitserregern/, 22.03.2022.

FOCUS (2012): Generic guidance for FOCUS surface water Scenarios. Retrieved 03 April 2023, 1.2, from https://esdac.jrc.ec.europa.eu/public_path/projects_data/focus/sw/docs/Generic%20FOCUS_SWS_vc1.4.pdf, 03.04.2023.

Fox, J.; Weisberg, S. (2019): An {R} Companion to Applied Regression. from https://socialsciences.mcmaster.ca/jfox/Books/Companion/, 10.10.2023.

Franke, A. C.; Kempenaar, C.; Holterman, H. J.; van de Zande, J. C. (2010): Spray Drift from Knapsack Sprayers - A study conducted within the framework of the Sino-Dutch Pesticide Environmental Risk Assessment Project PERAP. Plant Research International, Wageningen UR-PRI. Report 658.

Fritz, B. K.; Hoffmann, W. C.; Czaczyk, Z.; Bagley, W.; Kruger, G.; Henry, R. (2012): Measurements and classification methods using the ASAE S572.1 reference nozzles. Journal of Plant Protection Research. 52: 447-457.

Ganzelmeier, H.; Rautmann, D.; Spangenberg, R.; Streloke, M.; Herrmann, M.; Wenzelburger, H.-J.; Walter, H.-F. (1995): Studies on the spray drift of plant protection products. Blackwell, Berlin.

Gaytan, I.; Nicolas, B.; Gouriou, F.; Leru, J. P.; Mallarach, J. (2018): Effect of working pressure, fluid temperature, nozzle type and nozzle orifice size, on spray characteristics using viscous feed additive DL-2-hydroxy-4-(methylthio)-butanoic-acid. Powder Technology. 336: 383-392, http://doi.org/10.1016/j.powtec.2018.05.045.

Gil, E.; Balsari, P.; Gallart, M.; Llorens, J.; Marucco, P.; Andersen, P. G.; Fàbregas, X.; Llop, J. (2014): Determination of drift potential of different flat fan nozzles on a boom sprayer using a test bench. Crop Protection. 56: 58-68, https://doi.org/10.1016/j.cropro.2013.10.018.

Gregorio, E.; Torrent, X.; Planas de Marti, S.; Solanelles, F.; Sanz, R.; Rocadenbosch, F.; Masip, J.; Ribes-Dasi, M.; Rosell-Polo, J. R. (2016): Measurement of Spray Drift with a Specifically Designed Lidar System. Sensors. 16, http://doi.org/10.3390/s16040499.

Grella, M.; Miranda-Fuentes, A.; Marucco, P.; Balsari, P.; Gioelli, F. (2020): Development of Drift-Reducing Spouts For Vineyard Pneumatic Sprayers: Measurement of Droplet Size Spectra Generated and Their Classification. Applied Sciences. 10: 7826.

Grisso, R.; Askew, S. D.; McCall, D. (2019): Nozzles - Selection and Sizing. Virginia Tech. 442-032.

Grupo Sanz (2019a): Pulmic Fenix. from https://gruposanz.es/wp-content/uploads/2019/08/7391.Pulmic-Fenix.pdf, 07.08.2023.

Grupo Sanz (2019b): Pulmic Fenix 35. from https://gruposanz.es/wp-content/uploads/2019/08/8220.Pulmic-Fenix-35.pdf, 07.08.2023.

Grupo Sanz (2019c): Pulmic Fenix Insect. from https://gruposanz.es/wp-content/uploads/2019/08/2566.Pulmic-Fenix-Insect.pdf, 07.08.2023.

Grupo Sanz (2019d): Pulmic Fenix Pure. from https://gruposanz.es/wp-content/uploads/2019/08/8718.Pulmic-Fenix-Pure.pdf, 07.08.2023.

Grupo Sanz (2019e): Pulmic Fenix Pure 35. from https://gruposanz.es/wp-content/uploads/2019/08/8621.Pulmic-Fenix-Pure-35.pdf, 07.08.2023.

Grupo Sanz (2019f): Pulmic Taurus AIR+. from https://gruposanz.es/wp-content/uploads/2019/08/6981.Pulmic-Taurus-Air-Plus.pdf, 08.05.2023.

Guarany (2023a): 6l ULV Knapsack Nebuliser from https://www.guaranyind.com.br/en/equipment/6l-ulv-knapsack-nebuliser, 08.05.2023.

Guarany (2023b): 11l Granule Applicator / ULV – LV Nebuliser from https://www.guaranyind.com.br/en/equipment/11l-granule-applicator--ulv--lv-nebuliser, 08.05.2023.

Helck, C.; Herbst, A. (1998): Drift-Potential-Index - eine neue Kennzahl zur Beurteilung von Pflanzenschutzdüsen hinsichtlich ihres Abdriftpotentials. Nachrichtenblatt des Deutschen Pflanzenschutzdienstes. 50: 225-232.

Herbst, A. (2001): A Method to Determine Spray Drift Potential from Nozzles and its Link to Buffer Zone Restrictions. In: ASAE Annual International Meeting, 01-1047, Sacramento, California, USA.

Herbst, A.; He, X. (2008): A survey on knapsack sprayers and their use in China. Aspects of Applied Biology. 86.

Herbst, A.; Wygoda, H.-J. (2006): Pyranin – ein fluoreszierender Farbstoff für applikationstechnische Versuche (Pyranine – a fluorescent tracer dye for experiments on application techniques). Nachrichtenbl. Deut. Pflanzenschutzd. 58: 1-7.

Hewitt, A. J.; Johnson, D. R.; Fish, J. D.; Hermansky, C. G.; Valcore, D. L. (2002): Development of the Spray Drift Task force database for aerial applications. Environmental Toxicology and Chemistry. 21: 648-658, https://doi.org/10.1002/etc.5620210326.

Hilz, E.; Vermeer, A. W. P. (2013): Spray drift review: The extent to which a formulation can contribute to spray drift reduction. Crop Protection. 44: 75-83, http://doi.org/10.1016/j.cropro.2012.10.020.

Hoffmann, W. C.; Walker, T. W.; Fritz, B. K.; Farooq, M.; Smith, V. L.; Robinson, C. A.; Szumlas, D.; Lan, Y. (2009): Spray characterization of ultra-low-volume sprayers typically used in vector control. Journal of the American Mosquito Control Association. 25: 332-337, https://doi.org/10.2987/09-5883.1.

Hoffmann, W. C.; Walker, T. W.; Smith, V. L.; Martin, D. E.; Fritz, B. K. (2007): Droplet-size characterization of handheld atomization equipment typically used in vector control. J Am Mosq Control Assoc. 23: 315-320, http://doi.org/10.2987/8756-971x(2007)23[315:Dcohae]2.0.Co;2.

Hofman, V.; Solseng, E. (2004): Spray Equipment and Calibration. from https://www.ag.ndsu.edu/publications/crops/spray-equipment-and-calibration, 25.03.2020.

Holland, J. M.; Jepson, P. C. (1996): Droplet dynamics and initial field tests for microencapsulated pesticide formulations applied at ultra low volume using rotary atomisers for control of locusts and grasshoppers. Pesticide Science. 48: 125-134.

Holterman, H. J. (2003): Kinetics and evaporation of water drops in air. Institute of Agricultural and Environmental Engendering, Wageningen, IMAG Report 2003-2012.

Holterman, H. J.; van de Zande, J. C.; Porskamp, H. A. J.; Huijsmans, J. F. M. (1997): Modelling spray drift from boom sprayers. Computers and Electronics in Agriculture. 19: 1-22, https://doi.org/10.1016/S0168-1699(97)00018-5.

Horne, M. (2019): Knapsack Sprayers: Operators, Standards and Selection. Outlooks on Pest Management. 30: 171-175, https://doi.org/10.1564/v30_aug_07.

iGEBA (2014a): Thermal Fog Generator EVO 35. from https://igeba.de/wp-content/uploads/EVO35-Leaflet-EN.pdf, 14.04.2023.

iGEBA (2014b): Thermal Fog Generators. from https://igeba.de/wp-content/uploads/Leaflet-Thermal-Fog-GeneratorsEN.pdf, 14.04.2023.

iGEBA (2015a): Thermal Fog Generator TF 34. from https://igeba.de/wp-content/uploads/TF-34-Leaflet-EN.pdf, 17.04.2023.

iGEBA (2015b): Thermal Fog Generator TF 35. from https://igeba.de/wp-content/uploads/TF35-Leaflet-EN.pdf, 17.04.2023.

iGEBA (2015c): ULV Aerosol Kaltnebelgeräte. from https://igeba.de/wp-content/uploads/Prospekt-ULV-Aerosol-Generatoren-DE-2.pdf, 17.04.2023.

iGEBA (2016): Power Knapsack Sprayer PORT 423. from https://igeba.de/wp-content/uploads/Port423-ES5M-ES10M-Leaflet-EN-07-2016.pdf, 17.04.2023.

ISO (2005): ISO 22866:2005 - Equipment for crop protection — Methods for the field measurement of spray drift. Retrieved 03.04.2023, from https://www.iso.org/standard/35161.html, 03.04.2023.

ISO (2008): ISO 22856:2008 - Equipment for crop protection - Methods for the laboratory measurement of spray drift - Wind Tunnels.

ISO (2018): ISO 25358:2018 - Crop protection equipment — Droplet-size spectra from atomizers — Measurement and classification. Retrieved 03 April 2023, from https://www.iso.org/standard/66412.html, 03.04.2023.

ISO (2020): ISO 5681:2020 - Equipment for crop protection — Vocabulary. from https://www.iso.org/standard/72299.html, 27.04.2023.

JKI (2011): Pflanzenschutzgeraeteliste. from https://wissen.julius-kuehn.de/mediaPublic/AT-Dokumente/02-Pflanzenschutztechnik/Geraetepruefung/AT-Pflanzenschutzgeraeteliste-bis-2012.pdf, 17.03.2022.

JKI (2013a): Guideline for the testing of plant protection equipment - 2-2.1 Procedure for the registration of plant protection equipment in the section “drift-reduction” of the register of loss reducing equipment of the descriptive list. from https://wissen.julius-kuehn.de/mediaPublic/AT-Dokumente/01-Antraege-Richtlinien/guidelines/2-2.1-Procedure-for-Registration-of-DRT.pdf, 29.10.2019.

JKI (2013b): Guideline for the testing of plant protection equipment - 7-1.5 Measuring direct drift when applying Plant Protection Products outdoors. from https://wissen.julius-kuehn.de/mediaPublic/AT-Dokumente/01-Antraege-Richtlinien/guidelines/7-1.5-Measuring-direct-drift-when-applying-Plant-Protection-Products-outdoors.pdf, 08.03.2023.

JKI (2013c): Richtlinie für die Prüfung von Pflanzenschutzgeräten - 1-1.7 Anforderungen an Nebelgeräte. from https://wissen.julius-kuehn.de/mediaPublic/AT-Dokumente/01-Antraege-Richtlinien/Richtlinien/1-1.7-Anforderungen-an-Nebelgeraete.pdf.

JKI (2013d): Richtlinie für die Prüfung von Pflanzenschutzgeräten - 7-1.5 Messung der direkten Abdrift beim Ausbringen von flüssigen Pflanzenschutzmitteln im Freiland. from https://wissen.julius-kuehn.de/mediaPublic/AT-Dokumente/01-Antraege-Richtlinien/Richtlinien/7-1.5-Messung-der-direkten-Abdrift-beim-Ausbringen-von-fluessigen-Pflanzenschutzmitteln-im-Freiland.pdf, 08.03.2023.

JKI (2014): Test Report of the JKI for Flatfan nozzle Lechlner ID-120-05 POM. from https://psmvt6.julius-kuehn.de/anwendung/PDFs/G1966Bericht_e_Vers1_2.pdf, 05.10.2018.

JKI (2016a): Prüfbericht des JKI - Tragbares Nebelgerät pulsFOG K-22-STD.

JKI (2016b): Prüfbericht des JKI - Tragbares Nebelgerät pulsFOG K-30-STD.

JKI (2018): Universaltabelle für verlustmindernde Flachstrahldüsen (Universal table of loss reducing flat fan nozzles). from https://wissen.julius-kuehn.de/mediaPublic/AT-Dokumente/03-Abdrift/03-Universaltabellen-fuer-verlustmindernde-Flachstrahlduesen-90Prozent.pdf, 05.10.2018.

JKI (2020): Liste Agrarinvestitionsförderungsprogramm (List of agricultural investment promotion program). from https://www.julius-kuehn.de/media/Institute/AT/PDF_RichtlinienListenPruefberichte/AFP-Foerderung/Liste__AFP-Foerderung.xlsx, 20.04.2020.

JKI (2021): Richtlinie für die Prüfung von Pflanzenschutzgeräten - 7-1.8 Messung des Abdriftpotenzials von Düsen im Windkanal. from https://wissen.julius-kuehn.de/mediaPublic/AT-Dokumente/01-Antraege-Richtlinien/Richtlinien/7-1.8-Abdriftmessung-im-Windkanal-2021.pdf, 31.01.2023.

JKI (2022a): Prüfbericht des JKI - Tragbares Nebelgerät pulsFOG K-10-STD.

JKI (2022b): Tabelle der Abdrifteckwerte (Table of basic drift values). from https://wissen.julius-kuehn.de/mediaPublic/AT-Dokumente/03-Abdrift/Tabelle-der-Abdrifteckwerte-.xlsx, 20.12.2022.

JKI (2022c): Verzeichnis Verlustmindernde Geräte (List of Loss Reducing Devices). from https://wissen.julius-kuehn.de/mediaPublic/AT-Dokumente/03-Abdrift/Verzeichnis-Verlustmindernde-Geraete.xlsx, 10.02.2023.

JKI (2023): Dokumentenprüfung. from https://www.julius-kuehn.de/at/geraetepruefung, 22.03.2023.

Johnstone, D. R.; Cooper, J. F.; Dobson, H. M. (1987): The availability and fall-out of an insecticidal aerosol dispersed from aircraft during operations for control of tsetse fly in Zimbabwe. Atmospheric Environment (1967). 21: 2311-2321, https://doi.org/10.1016/0004-6981(87)90366-0.

Jong, A. d.; Michielsen, J. M. G. P.; Stallinga, H.; Zande, J. C. v. d. (2000): Effect of sprayer boom height on spray drift. Mededelingen - Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen, Universiteit Gent. 65: 919-930.

Kampen, H.; Kronefeld, M.; Scheuch, D.; Werner, D. (2012): Further specimens of the Asian tiger mosquito Aedes albopictus (Diptera, Culicidae) trapped in southwest Germany. Parasitology research. 112: 905–907, https://doi.org/10.1007/s00436-012-3128-y.

Kashdan, J. T.; Shrimpton, J. S.; Whybrew, A. (2003): Two-Phase Flow Characterization by Automated Digital Image Analysis. Part 1: Fundamental Principles and Calibration of the Technique. Particle & Particle Systems Characterization. 20: 387-397, https://doi.org/10.1002/ppsc.200300897.

Knewitz, H.; Weisser, P.; Koch, H. (2002): Drift-reducing spray application in orchards and biological efficacy of pesticides. Aspects of Applied Biology. 66.

Knoche, M. (1994): Effect of droplet size and carrier volume on performance of foliage-applied herbicides. Crop Protection. 13: 163-178, https://doi.org/10.1016/0261-2194(94)90075-2.

Lading, L.; Wigley, G.; Buchhave, P. (1994): Optical Diagnostics for Flow Processes. Springer.

Langkamp-Wedde, T. (2023): Basic drift values in the authorisation procedure for biocidal products (PT 18). Journal für Kulturpflanzen. 75: 165–170, http://doi.org/10.5073/JfK.2023.05-06.06.

Langkamp-Wedde, T.; Rautmann, D.; Von Hörsten, D. (2020): Reduction of drift in spray application/nebulization of biocides - Derivation of risk reduction measures and device requirements. from https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2020-05-04_texte_55-2020_nebulization-biocides.pdf, 05.06.2020.

Lazzaro, L.; Otto, S.; Zanin, G. (2008): Role of hedgerows in intercepting spray drift: Evaluation and modelling of the effects. Agriculture, Ecosystems and Environment. 123: 317-327, https://doi.org/10.1016/j.agee.2007.07.009.

Lofgren, C. S. (1970): Ultralow Volume Applications of Concentrated Insecticides in Medical and Veterinary Entomology. Annual Review of Entomology. 15: 321-342, http://doi.org/10.1146/annurev.en.15.010170.001541.

Lofgren, C. S.; Anthony, D. W.; Mount, G. A. (1973): Size of Aerosol Droplets Impinging on Mosquitoes as Determined with a Scanning Electron Microscope1. Journal of Economic Entomology. 66: 1085-1088, https://doi.org/10.1093/jee/66.5.1085.

London Foggers (2022a): 9-10. from https://londonfoggers.com/wp-content/uploads/2022/01/9-10H_SPEC_SHEET.pdf, 13.04.2023.

London Foggers (2022b): 18-20. from https://londonfoggers.com/wp-content/uploads/2020/03/18-20_2020_FL.pdf, 23.03.2023.

London Foggers (2022c): Colt4. from https://londonfoggers.com/wp-content/uploads/2020/03/COLT_2020_FL.pdf, 13.04.2023.

London Foggers (2022d): F500 Thermal. from https://londonfoggers.com/wp-content/uploads/2020/03/F500_2020_FL.pdf, 14.04.2023.

London Foggers (2022e): MAG. from https://londonfoggers.com/wp-content/uploads/2020/03/MAG_2020_FL.pdf, 13.04.2023.

Longray (2013a): Longray catalogue. from https://longrayfog.com/wp-content/uploads/2015/07/2013-Longray-catalogue.pdf, 28.04.2023.

Longray (2013b): TS 95 - Longray catalogue. from https://longrayfog.com/wp-content/uploads/2015/07/2013-Longray-catalogue.pdf, 28.04.2023.

Longray (2023a): LR 4P. from https://longray.eu/en/ulv-cold-fogger/28-truck-mounted-ulv-cold-fogger-lr-4p.html, 28.04.2023.

Longray (2023b): LR G. from https://longray.eu/en/ulv-cold-fogger/29-truck-mounted-ulv-cold-fogger-lr-g.html, 28.04.2023.

Longray (2023c): Pioneer Eco-Backpack Sprayer. from https://azelisaes-us.com/wp-content/uploads/Pioneer-Eco-Backpack-Sprayer-copy.pdf, 28.04.2023.

Lothrop, H.; Lothrop, B.; Gomsi, D.; Reisen, W. (2008): Intensive Early Season Adulticide Applications Decrease Arbovirus Transmission Throughout the Coachella Valley, Riverside County, California. Vector borne and zoonotic diseases (Larchmont, N.Y.). 8: 475-489, http://doi.org/10.1089/vbz.2007.0238.

Mantis ULV (2023): MANKAR - technische Daten. from https://www.mantis-ulv.com/sites/all/themes/cont/MANKAR-Datenblatt_2023-EN.pdf, 07.08.2023.

Martelloni, L.; Frasconi, C.; Sportelli, M.; Fontanelli, M.; Raffaelli, M.; Peruzzi, A. (2020): Flaming, Glyphosate, Hot Foam and Nonanoic Acid for Weed Control: A Comparison. Agronomy. 10, https://doi.org/10.3390/agronomy10010129.

Maruyama (2017a): MM181 ULV-Fogger. from https://azelisaes-us.com/wp-content/uploads/MARUYAMA-MM181-ULV-FOGGER.pdf, 28.04.2023.

Maruyama (2017b): MM300 Mister. from https://azelisaes-us.com/wp-content/uploads/MARUYAMA-MD300-DUSTER.pdf, 28.04.2023.

Matthews, G. A. (2016): Pesticides - Health, Safety and the Environment. John Wiley & Sons, Ltd, Chichester, West Sussex, UK.

Matthews, G. A.; Bateman, R.; Miller, P. (2014): Pesticide Application Methods - Fourth Edition. Blackwell Publishing Ltd.

McAuliffe, D.; Gray, V. P. (2002): ApplicationTechnology - Problems and Opportunities with Knapsack Sprayers, Including the CFValve™ or Constant Flow Valve.

Messenger, K. (1963): Low volume aerial spraying will be boon to applicator. Agric. Chem. 18: 63-66.

Messenger, K. (1964): Low volume aerial spraying. Agric. Chem. 19: 61-64.

Meyer, R. P.; Reisen, W. K.; Eberle, M. E.; Milby, M. M. (1986): The nightly host-seeking rhythms of several Culicine mosquitoes (*Diptera: cullcidae*) in the southern San Joaquin Valley of California. In: 54th Annual Conference ofthe California Mosquito and Vector Control Association, 52, 136.

Micron Group (2022): MiCRONAIR AU5000 - An efficient rotary atomiser for aerial spraying. from https://www.microngroup.com/files/au5000_leaflet.pdf, 09.03.2022.

Micron Group (2023a): AU8000 - A knapsack mistblower using rotary atomiser technology. from https://www.microngroup.com/files/au8000_hr_solo_423_web_a4.pdf, 02.05.2023.

Micron Group (2023b): AU8115MS - A vehicle-mounted sprayer using rotary atomiser technology. from https://www.microngroup.com/files/au8115ms_web_small.pdf, 02.05.2023.

Micron Group (2023c): AU9000 - A compact and efficient ULV cold fogging machine. from https://www.microngroup.com/files/au9000_leaflet_micron_eng_alta.pdf, 02.05.2023.

Micron Group (2023d): Handy - An efficient CDA sprayer for weed control. from https://www.microngroup.com/files/handy.pdf, 07.08.2023.

Micron Group (2023e): Herbi 4 - An ideal choice for band weed control. from https://www.microngroup.com/files/herbi4.pdf, 16.05.2023.

Micron Group (2023f): Herbidome 600 - Hand-held shielded sprayer for weed control. from https://www.microngroup.com/files/herbidome600.pdf, 16.05.2023.

Micron Group (2023g): Herbiflex 4 - An economical hand-held sprayer for weed control. from https://www.microngroup.com/files/herbiflex4.pdf, 16.05.2023.

Micron Group (2023h): Microfog 9ES/35ES/9EP/35EP - A Range of Robust and Durable Thermal Foggers. from https://www.microngroup.com/files/5902_microfog_35es_35ep_9es_and_9ep_english_-_low_res.pdf, 02.05.2023.

Micron Group (2023i): Micromax - A rotary atomiser for vehicle mounted spraying. from https://www.microngroup.com/files/micromax.pdf, 16.05.2023.

Micron Group (2023j): Micron AU8120 Airblast Atomiser. from https://www.microngroup.com/micronair_au_8120_airblast_atomiser, 07.08.2023.

Micron Group (2023k): MiCRONAIR AU4000 - A rotary atomiser for ultra low volume spraying. from https://www.microngroup.com/files/au4000_leaflet.pdf, 16.05.2023.

Micron Group (2023l): MiCRONAIR AU6539 - A versatile electric atomiser for use on helicopters. from https://www.microngroup.com/files/au6539.pdf, 16.05.2023.

Micron Group (2023m): MirofitPro - A lightweight CDA sprayer for the professional user. from https://www.microngroup.com/files/microfitpro.pdf, 16.05.2023.

Micron Group (2023n): Spraydome - Shielded sprayer for weed control in bush crops, plantations and amenity areas. from https://www.microngroup.com/files/spraydome_v2.pdf, 07.08.2023.

Micron Group (2023o): Turbofan - Air-assisted spray head for low volume spraying. from https://www.microngroup.com/files/turbofan_1.pdf, 07.08.2023.

Micron Group (2023p): Undavina - Shielded weed control for vineyards and orchards. from https://www.microngroup.com/files/undavina_v2.pdf, 07.08.2023.

Micron Group (2023q): Varidome - A range of efficient band sprayers. from https://www.microngroup.com/files/4462_varidomebrochurelr.pdf, 07.08.2023.

Micron Group (2023r): X-1 - a spinning disc rotary atomiser. from https://www.microngroup.com/micron_x-1, 07.08.2023.

Miller, A.; Bellinder, R. (2001): Herbicide Application Using a Knapsack Sprayer. New Delhi-110 012, India: Rice-Wheat Consortium for the Indo-Gangetic Plains. pp 12.

Miller, P. (2003): The measurement of spray drift. Pesticide Outlook. 14: 205-209, http://doi.org/10.1039/b311466j.

Miranda-Fuentes, A.; Marucco, P.; Gonzalez-Sanchez, E. J.; Gil, E.; Grella, M.; Balsari, P. (2018): Developing strategies to reduce spray drift in pneumatic spraying in vineyards: Assessment of the parameters affecting droplet size in pneumatic spraying. Sci Total Environ. 616-617: 805-815, http://doi.org/10.1016/j.scitotenv.2017.10.242.

Mount, G. A. (1998): A critical review of ultralow-volume aerosols of insecticide applied with vehicle-mounted generators for adult mosquito control. Journal of the American Mosquito Control Associntion. 14: 305-334.

Mount, G. A.; Biery, T. L.; Haile, D. G. (1996): A review of ultralow-volume aerial sprays of insecticide for mosquito control. Journal of the American Mosquito Control Association. 12 4: 601-618.

Nasr, G. G.; Yule, A. J.; Bending, L. (2002): Industrial Sprays And Atomization. Springer-Verlag London Ltd.

Nuyttens, D.; Baetens, K.; De Schampheleire, M.; Sonck, B. (2007): Effect of nozzle type, size and pressure on spray droplet characteristics. Biosystems Engineering. 97: 333-345, https://doi.org/10.1016/j.biosystemseng.2007.03.001.

Nuyttens, D.; Schampheleire, M.; Brusselman, E.; Dekeyser, D.; Verboven, P. (2010): Drift from Field Crop Sprayers using an Integrated Approach: Results of a 5 Year Study. In: ASABE Annual International Meeting, 4.

Nuyttens, D.; Schampheleire, M.; Steurbaut, W.; Baetens, K.; Verboven, P.; Nicolaï, B.; Ramon, H.; Sonck, B. (2006a): Experimental study of factors influencing the risk of drift from field sprayers, Part 1: Meteorological conditions. Aspects of Applied Biology. 77.

Nuyttens, D.; Schampheleire, M.; Steurbaut, W.; Baetens, K.; Verboven, P.; Nicolaï, B.; Ramon, H.; Sonck, B. (2006b): Experimental study of factors influencing the risk of drift from field sprayers, Part 2: Spray application technique. Aspects of Applied Biology. 77: 331-339.

OECD (2008): Emission Scenario Document for Insecticides, Acaricides and Products to Control Other Arthropods for Household and Professional Uses. OECD Publishing, Paris.

Ooms, J. (2021): magick: Advanced Graphics and Image-Processing in R. from https://CRAN.R-project.org/package=magick, 10.10.2023.

Piccolomini, A. M.; Flenniken, M. L.; O'Neill, K. M.; Peterson, R. K. D. (2018): The Effects of an Ultra-low-Volume Application of Etofenprox for Mosquito Management on Megachile rotundata (Hymenoptera: Megachilidae) Larvae and Adults in an Agricultural Setting. Journal of Economic Entomology. 111: 33-38, https://doi.org/10.1093/jee/tox343.

Pluskota, B.; Storch, V.; Braunbeck, T.; Beck, M.; Becker, N. (2008): First record of Stegomyia albopicta (Skuse) (Diptera: Culicidae) in Germany. European Mosquito Bulletin. 26: 1-5.

Porskamp, H. A. J.; Michielsen, J. M. G. P.; van de Zande, J. C. (1997): Emission-reducing pesticide application in flowerbulb growing. Drift deposition of an air-assisted field sprayer, a sprayer with a shielded sprayer boom and a tunnel sprayer. IMAG-DLO Report 97-08, Instituut voor Milieuen Agritechniek, Wageningen.

Pringnitz, B. A.; Hanna, H. M.; Ellerhoff, J. (2001): Selecting the Correct Nozzle to Reduce Spray Drift. Agriculture and Environment Extension Publications. 184.

pulsFOG (2010a): K-10-SP. from https://www.pulsfog.de/sources/products/product%20bulletin/K-10-SP_NOV_2010-2.pdf, 03.05.2023.

pulsFOG (2010b): K-22-10-(20-)STD / K-22-10-(20-)O. from https://www.pulsfog.de/sources/products/product%20bulletin/K-22-10__small_tubular_frame__11-OCT-2011.pdf, 03.05.2023.

pulsFOG (2010c): K-22-20-Bio. from https://www.pulsfog.de/sources/products/product%20bulletin/K-22-20-BIO__large_tubular_frame_22-7-2011.pdf, 03.05.2023.

pulsFOG (2010d): K-22-STD/K-22-O. from https://www.pulsfog.de/sources/products/product%20bulletin/K-22-STD_und_O__11-OCT-11.pdf, 03.05.2023.

pulsFOG (2010e): K-30-20-BIO (large 2). from https://www.pulsfog.de/sources/products/product%20bulletin/K-30-20-BIO__large_tubular_frame__2x65_ltr__12-NOV-10.pdf, 03.05.2023.

pulsFOG (2010f): K-30-20-BIO (large). from https://www.pulsfog.de/sources/products/product%20bulletin/K-30-20-BIO__large_tubular_frame__2x55_ltr__12-NOV-10.pdf, 03.05.2023.

pulsFOG (2010g): K-30-20-BIO (small). from https://www.pulsfog.de/sources/products/product%20bulletin/K-30-20-BIO__small_tubular_frame_2x55_ltr__10-NOV-10.pdf, 03.05.2023.

pulsFOG (2010h): K-30-20-STD / K-30-20-O (small). from https://www.pulsfog.de/sources/products/product%20bulletin/K-30-20__small_tubular_frame__1x55_ltr_11-OCT-2011.pdf, 03.05.2023.

pulsFOG (2010i): K-30-STD/K-30-O. from https://www.pulsfog.de/sources/products/product%20bulletin/K-30-STD_und_O__11-OCT-2011.pdf, 03.05.2023.

pulsFOG (2010j): tracFOG. from https://www.pulsfog.de/sources/products/product%20bulletin/TracFOG_21.1.09(1).pdf, 04.05.2023.

pulsFog (2012): K-30-20-STD / K-30-20-O (large). from https://www.pulsfog.de/sources/products/product%20bulletin/K-30-20__large_tubular_frame_11-OCT-2011.pdf, 04.05.2023.

pulsFOG (2017a): K-30-Bio. from https://www.pulsfog.de/sources/products/product%20bulletin/pulsFOG_Product_Bulletin_K-30-BIO.pdf, 03.05.2023.

pulsFOG (2017b): K-50. from https://www.pulsfog.de/sources/products/product%20bulletin/pulsFOG_Product_Bulletin_K-50.pdf, 03.05.2023.

pulsFOG (2018a): K-10-Desert. from https://www.pulsfog.de/sources/products/product%20bulletin/pulsFOG_Product_Bulletin_K-10-DESERT.pdf, 03.05.2023.

pulsFOG (2018b): K-22-Bio. from https://www.pulsfog.de/sources/products/product%20bulletin/pulsFOG_Product_Bulletin_K-22-BIO.pdf, 03.05.2023.

R Core Team (2021): The R Project for Statistical Computing. from www.r-project.org, 16.06.2023.

Rautmann, D.; Streloke, M.; Winkler, R. (2001): New basic drift values in the authorization procedure for plant protection products. In: Workshop on Risk Assessment and Risk Mitigation Measures in the Context of the Authorization of Plant Protection Products (WORMM), 381, 133-141, Berlin-Dahlum.

Ruktanonchai, D. J.; Stonecipher, S.; Lindsey, N.; McAllister, J.; Pillai, S. K.; Horiuchi, K.; Delorey, M.; Biggerstaff, B. J.; Sidwa, T.; Zoretic, J.; Nasci, R.; Fischer, M.; Hills, S. L. (2014): Effect of aerial insecticide spraying on West Nile virus disease--north-central Texas, 2012. Am J Trop Med Hyg. 91: 240-245, http://doi.org/10.4269/ajtmh.14-0072.

Sarkar, D. (2008): Lattice: Multivariate Data Visualization with R. from http://lmdvr.r-forge.r-project.org, 16.06.2023.

Sarkar, D.; Andrews, F. (2019): latticeExtra: Extra Graphical Utilities Based on Lattice. from https://CRAN.R-project.org/package=latticeExtra, 16.06.2023.

Sayer, H. J. (1959): An Ultra-low-volume Spraying Technique for the Control of the Desert Locust, Schistocerca gregaria (Forsk.). Bulletin of Entomological Research. 50: 371-386, http://doi.org/10.1017/S0007485300054638.

Schleier III, J. J.; Peterson, R. K.; Irvine, K. M.; Marshall, L. M.; Weaver, D. K.; Preftakes, C. J. (2012): Environmental fate model for ultra-low-volume insecticide applications used for adult mosquito management. Science of the Total Environment. 438: 72-79, https://doi.org/10.1016/j.scitotenv.2012.07.059.

Sehsah, E. M. E.; Ganzelmeier, H. (2010): Comperastion study on low pressure EMTF nozzles based on droplets size characteristics. MISR Journal of Agricultural Engineering. 27: 122-140.

Skoog, F. E.; Cowan, F. T.; Messenger, K. (1965): Ultra-Low-Volume Aerial Spraying of Dieldrin and Malathion for Rangeland Grasshopper Control12. Journal of Economic Entomology. 58: 559-565, http://doi.org/10.1093/jee/58.3.559.

Slaff, M.; Crans, W. J. (1981): The host seeking activity of *Culex salinarius*. Mosquito News. 41: 443-447.

SOLO (2021): Produktinformation - ULV-Düse 49480. from https://shop.solo.global/media/10/d0/e8/1617974488/Produktinfo_ULV_DE.pdf, 23.02.2023.

SOLO (2022): 466 Mist Blower. from https://us.solo.global/index.php?controller=attachment&id_attachment=150, 09.05.2023.

Southcombe, E. S. E.; Miller, P. C. H.; Ganzelmeier, H.; van de Zande, J. C.; Miralles, A.; Hewitt, A. J. (1997): The international (BCPC) spray classification system including a drift potential factor. In: The Brighton Crop Protection Conference - Weeds.

Spencer, J.; Dent, D. R. (1991): Walking speed as a variable in knapsack sprayer operation: perception of speed and the effect of training. Trop. pest manage. 37: 321-323, https://doi.org/10.1080/09670879109371607.

Stephenson, G. R.; Ferris, I. G.; Holland, P. T.; Nordberg, M. (2006): Glossary of terms relating to pesticides (IUPAC Recommendations 2006). Pure and Applied Chemistry. 78: 2075–2154, https://doi.org/10.1351/pac200678112075.

STIHL (2020a): STIHL SR 200. from https://m.stihl.at/controls/baonline/Download.aspx?Document=00_457.pdf&Name=STIHL+SR+200, 08.05.2023.

STIHL (2020b): STIHL SR 430, 450. from https://www.stihlusa.com/WebContent/CMSFileLibrary/instructionmanuals/STIHL-SR-430-450-Owners-Instruction-Manual.pdf, 27.03.2023.

Świechowski, W.; Doruchowski, G.; Godyń, A.; Hołownicki, R. (2014): Spray application quality as affected by spray volume, nozzles ans phenological growth stage of apples. Agricultural Engineering. 1: 229-237, http://doi.org/10.14654/ir.2014.149.024.

Swingtec (2019a): Fontan Mobilstar M. from https://dev.swingtec-gmbh.de/wp-content/uploads/2019/03/Fontan_Mobilstar.pdf, 03.05.2023.

Swingtec (2019b): Fontan Portastar S. from https://dev.swingtec-gmbh.de/wp-content/uploads/2019/03/Portastar-S.pdf, 03.05.2023.

Swingtec (2019c): Swingfog SN 50 - SN 50 PE - SN 50-10 - SN 50-10 PE. from https://dev.swingtec-gmbh.de/wp-content/uploads/2019/03/SN-50.pdf, 02.05.2023.

Swingtec (2019d): Swingfog SN 81 - SN 81 PE - SN 81 Pump - SN 81-20 PE. from https://dev.swingtec-gmbh.de/wp-content/uploads/2019/03/SN-81.pdf, 02.05.2023.

Swingtec (2019e): Swingfog SN 101 E - SN 101 M - SN 101 Pump. from https://dev.swingtec-gmbh.de/wp-content/uploads/2019/03/SN-101.pdf, 02.05.2023.

Taylor, W.; Womac, A.; Miller, P.; Taylor, B. (2004): An Attempt to Relate Drop Size to Drift Risk. In: Proceedings of the International Conference on Pesticide Application for Drift Management, 01/01.

Teejet (2013): User's guide to spray nozzles. from https://teejet.it/media/40076/user%27s%20guide%20to%20spray%20nozzles_2013_lo-res-sequential.pdf, 24.03.2020.

Tomahawk (2023a): Backpack Foggers TMD14. from https://www.solutionsstores.com/amfilerating/file/download/file_id/4791/, 28.04.2023.

Tomahawk (2023b): Battery Foggers eTMD14. from https://cdn.shopify.com/s/files/1/0277/2821/6112/files/eTMD14_Spec_Sheet.pdf?v=1677180788, 28.04.2023.

Tomahawk (2023c): ULV Nozzle with Droplet Size of 25-100 Microns for TMD14 Mist Blower. from https://tomahawk-power.com/collections/backpack-foggers/products/ulv-kit-for-tmd14-mist-blower, 16.05.2023.

UBA (2015): Die Asiatische Tigermücke Aedes albopictus - Fachinformation. from https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/flyer_die_asiatische_tigermuecke.pdf, 22.03.2022.

van de Zande, J.; Michielsen, J. M. G. P.; Stallinga, H. (2007): Spray drift and off-field evaluation of agrochemicals in the Netherlands. Plant Research International, Wageningen UR-PRI. Report 149.

van de Zande, J. C.; Holterman, H. J.; Huijsmans, J. F. M. (2016): Spray drift for the assessment of exposure of aquatic organisms to plant protecion products in the Netherlands. Plant Research International, Wageningen UR-PRI. 419, http://doi.org/10.13140/RG.2.1.2860.1848.

Vector Fog (2020): Vector Fog Catalogue 2020. from https://nebulizadoresml.com/wp-content/uploads/2021/02/Vectorfog_Catalog_2020.pdf, 03.05.2023.

Wenneker, M.; Zande; van de Zande, J. (2008): Spray drift reducing effects of natural windbreaks in orchard spraying. Aspects of Applied Biology. 84.

Werner, D.; Kronefeld, M.; Schaffner, F.; Kampen, H. (2012): Two invasive mosquito species, Aedes albopictus and Aedes japonicus japonicus, trapped in south-west Germany, July to August 2011. Eurosurveillance. 17: 1-4, https://doi.org/10.5167/uzh-61698.

White Fog (2020a): SM 700 Dual. from https://whitefog.com/wp-content/uploads/2020/06/06-SM700-Dual-Nozzle-Catalog.pdf, 04.05.2023.

White Fog (2020b): SM 700 Thermal Fogger. from https://whitefog.com/wp-content/uploads/2020/06/Vehicle-Truck-Car-Mounted-Thermal-Fogger-Fogging-Machine-SM700_Catalog.pdf, 04.05.2023.

White Fog (2020c): SM 900 Thermal Fogger. from https://whitefog.com/wp-content/uploads/2020/06/Car-Mount-Thermal-Fogger-Fogging-Oil-Water-Based-Fumigation-Machine-SM900.pdf, 04.05.2023.

White Fog (2020d): ULV 900. from https://whitefog.com/wp-content/uploads/2020/07/ULV_900.pdf, 04.05.2023.

White Fog (2020e): ULV 900 (2 Nozzle). from https://whitefog.com/wp-content/uploads/2020/07/ULV900_2_Nozzle.pdf, 04.05.2023.

White Fog (2020f): ULV 900 Twin. from https://whitefog.com/wp-content/uploads/2020/07/ULV900_Twin.pdf, 04.05.2023.

White Fog (2020g): ULV 1200 (2 Nozzle). from https://whitefog.com/wp-content/uploads/2020/07/ULV1200_2nozzle.pdf, 04.05.2023.

White Fog (2020h): ULV 1200 Cold Fogger. from https://whitefog.com/wp-content/uploads/2020/06/Vehicle-Truck-Car-Mounted-ULV-Cold-Fogger-Fogging-Machine-Generator_ULV1200.pdf, 04.05.2023.

White Fog (2020i): ULV 1200 Twin (2 Nozzle). from https://whitefog.com/wp-content/uploads/2020/07/ULV1200_Twin_2Nozzle.pdf, 04.05.2023.

White Fog (2020j): ULV 1200 Twin (4 Nozzle). from https://whitefog.com/wp-content/uploads/2020/06/ULV-Cold-Fogger-Disinfection-Sanitizer-Fogging-insecticide-Sprayer-ULV1200Twin-4Nozzle.pdf, 04.05.2023.

White Fog (2020k): ULV 1400 Colg Fogger and Mist Sprayer. from https://whitefog.com/wp-content/uploads/2020/07/ULV1400.pdf, 04.05.2023.

White Fog (2020l): ULV 2000 Cold Fogger and Mist Sprayer. from https://whitefog.com/wp-content/uploads/2020/06/ULV-Cold-Fogger-and-Mist-Sprayer-Machine.pdf, 04.05.2023.

White Fog (2022): Ultra Fogger. from https://whitefog.com/wp-content/uploads/2022/12/Ultra-Fogger-Catalog-GE.pdf, 04.05.2023.

WHO (2003): Space spray application of insecticides for vector and public health pest control : a practitioner's guide. World Health Organization, Geneva.

WHO (2018): Equipment for vector control - Specification guidelines. 2nd edition. from https://www.who.int/whopes/resources/9789241513821/en/, 07.10.2019.

Wickham, H. (2016): ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag, New York.

Wickham, H.; Bryan, J. (2019): readxl: Read Excel Files. from https://CRAN.R-project.org/package=readxl, 16.06.2023.

Wickham, H.; Girlich, M. (2022): tidyr: Tidy Messy Data. from https://CRAN.R-project.org/package=tidyr, 16.06.2023.

Wilson, M. C.; Ruppel, R. F.; Treece, R. E. (1965): Low-Volume Concentrate Sprays Applied by Aircraft for Control of the Cereal Leaf Beetle1. Journal of Economic Entomology. 58: 11-14, http://doi.org/10.1093/jee/58.1.11.

Yu, G. (2022): ggimage: Use Image in 'ggplot2'. from https://CRAN.R-project.org/package=ggimage, 10.10.2023.

Yule, A. J.; Dunkley, J. J. (1994): Atomization of Melts. Oxford University Press, UK.

A Appendix

A.1 Recommended basic drift values [%] for single application 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)	Motorised knapsack mistblower (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.

Source: own compilation, JKI

A.2 Recommended basic drift values [%] for twice application derived from the measured drift values for different application areas and devices, based on the 82nd percentile.

Distance [m]	Avenue			Forest edge	
	Cannon sprayer (pneumatic)	Cannon sprayer (hydraulic)	Helicopter (hydraulic)	Cannon sprayer (pneumatic)	Helicopter (hydraulic)
5	12.88	11.66	12.2	21.46*	7.99
10	10.81	9.08	9.27	21.46*	6.51
20	7.62	5.51	5.35	21.46*	4.32
30	5.37	3.34	3.08	15.55	2.87
50	2.67	1.23	1.03	7.42	1.26
75	1.11	0.35	0.26	2.94	0.45
85		0.21	0.15		
100	0.46			1.17	0.16

Source: own compilation, JKI

A.3 Recommended basic drift values [%] for triple application derived from the measured drift values for different application areas and devices, based on the 77th percentile.

Distance [m]	Avenue			Forest edge	
	Cannon sprayer (pneumatic)	Cannon sprayer (hydraulic)	Helicopter (hydraulic)	Cannon sprayer (pneumatic)	Helicopter (hydraulic)
5	11.57	10.27	10	20.78	5.3
10	9.76	8	7.52	20.78	4.36
20	6.95	4.85	4.25	20.78	2.96
30	4.94	2.94	2.41	14.82	2
50	2.5	1.08	0.77	7.07	0.92
75	1.07	0.31	0.19	2.8	0.35
85		0.19	0.1		
100	0.46			1.11	0.13

Source: own compilation, JKI

A.4 Table of recommended values of drift mitigation classes for the treatment of a solitary tree - Ground sediments in % of application rate calculated on the base of maximum values.

Distance [m]	Cannon sprayer (pneumatic)					Motorised knapsack mistblower (lifting platform)					UAV (hydraulic)				
	Maxi	50%	75%	90%	95%	Maxi	50%	75%	90%	95%	Maxi	50%	75%	90%	95%
5	4.2883	2.1442	1.0721	0.4288	0.2144	5.3203	2.6601	1.3301	0.5320	0.2660	56.9979	28.4990	14.2495	5.6998	2.8499
10	3.3231	1.6615	0.8308	0.3323	0.1662	3.9413	1.9707	0.9853	0.3941	0.1971	37.6380	18.8190	9.4095	3.7638	1.8819
20	1.9955	0.9977	0.4989	0.1995	0.0998	2.1631	1.0815	0.5408	0.2163	0.1082	16.4120	8.2060	4.1030	1.6412	0.8206
30	1.1983	0.5991	0.2996	0.1198	0.0599	1.1871	0.5936	0.2968	0.1187	0.0594	7.1565	3.5782	1.7891	0.7156	0.3578
50	0.4321	0.2160	0.1080	0.0432	0.0216	0.3576	0.1788	0.0894	0.0358	0.0179	1.3607	0.6804	0.3402	0.1361	0.0680
75	0.1207	0.0604	0.0302	0.0121	0.0060	0.0798	0.0399	0.0199	0.0080	0.0040	0.1708	0.0854	0.0427	0.0171	0.0085
85	0.0725	0.0363	0.0181	0.0073	0.0036										
100						0.0178	0.0089	0.0045	0.0018	0.0009	0.0215	0.0107	0.0054	0.0021	0.0011

Source: own compilation, JKI

A.5 Table of recommended values of drift mitigation classes for the treatment of an avenue - Ground sediments in % of application rate calculated on the base of median values.

Distance [m]	Cannon sprayer (pneumatic)					Cannon sprayer (hydraulic)					Helicopter (hydraulic)				
	Median	50%	75%	90%	95%	Median	50%	75%	90%	95%	Median	50%	75%	90%	95%
5	8.8743	4.4371	2.2186	0.8874	0.4437	6.3251	3.1625	1.5813	0.6325	0.3163	4.6471	2.3235	1.1618	0.4647	0.2324
10	7.3021	3.6510	1.8255	0.7302	0.3651	4.8284	2.4142	1.2071	0.4828	0.2414	3.4426	1.7213	0.8607	0.3443	0.1721
20	4.9439	2.4720	1.2360	0.4944	0.2472	2.8138	1.4069	0.7034	0.2814	0.1407	1.8894	0.9447	0.4723	0.1889	0.0945
30	3.3473	1.6737	0.8368	0.3347	0.1674	1.6397	0.8199	0.4099	0.1640	0.0820	1.0369	0.5185	0.2592	0.1037	0.0518
50	1.5344	0.7672	0.3836	0.1534	0.0767	0.5568	0.2784	0.1392	0.0557	0.0278	0.3123	0.1562	0.0781	0.0312	0.0156
75	0.5788	0.2894	0.1447	0.0579	0.0289	0.1444	0.0722	0.0361	0.0144	0.0072	0.0697	0.0348	0.0174	0.0070	0.0035
85						0.0841	0.0421	0.0210	0.0084	0.0042	0.0382	0.0191	0.0096	0.0038	0.0019
100	0.2183	0.1092	0.0546	0.0218	0.0109										

Source: own compilation, JKI

A.6 Table of recommended values of drift mitigation classes for the treatment of a forest edge - Ground sediments in % of application rate calculated on the base of median values.

Distance [m]	Cannon sprayer (pneumatic)					Helicopter (hydraulic)				
	Median	50%	75%	90%	95%	Median	50%	75%	90%	95%
5	14.1220	7.0610	3.5305	1.4122	0.7061	9.9326	4.9663	2.4831	0.9933	0.4966
10	14.1220	7.0610	3.5305	1.4122	0.7061	8.0110	4.0055	2.0028	0.8011	0.4006
20	14.1220	7.0610	3.5305	1.4122	0.7061	5.2112	2.6056	1.3028	0.5211	0.2606
30	9.4952	4.7476	2.3738	0.9495	0.4748	3.3900	1.6950	0.8475	0.3390	0.1695
50	4.8104	2.4052	1.2026	0.4810	0.2405	1.4345	0.7173	0.3586	0.1435	0.0717
75	2.0560	1.0280	0.5140	0.2056	0.1028	0.4896	0.2448	0.1224	0.0490	0.0245
85										
100	0.8788	0.4394	0.2197	0.0879	0.0439	0.1671	0.0835	0.0418	0.0167	0.0084

Source: own compilation, JKI