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Reduction of drift in spray application/ nebulization of biocides - Derivation of risk reduction measures and device requirements

Final Report

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Reduction of drift in spray application/ nebulization of biocides - Derivation of risk reduction measures and device requirements

Final report

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Abstract: Reduction of drift in spray application/ nebulization of biocides - Derivation of risk reduction measures and device requirements

Biocidal and plant protection products belong to the group of pesticides and serve to protect humans, animals and materials against pests and vermin. On the German market, most of the biocidal products have not yet fully been evaluated under the Biocidal Products Regulation 528/2012 due to transitional regulations, so there is still very little knowledge about the way in which biocidal products are used. The goal of this study was to identify and to investigate the areas with high drift potential. It turns out, that the areas with the highest drift potentials are the control of oak processionary moth (OPM) with sprayers and the control of flying and crawling insects in the surrounding of buildings with knapsack sprayers. Experimental results show, that in all applications the drift decreased exponentially with the distance from the treated area. The highest drift values were measured using cannon sprayers at the forest edge, slightly lower drift values in the avenue and considerably lower drift values when a solitary tree was treated. Using a helicopter, lower basic drift values of 50% were observed, if a nozzle with taller drops was used. These first results show that it is likely that biocidal products drift into non-target areas, leading to potential risks for non-target organisms. However, the results show possibilities to reduce basic drift values by choosing the technology least prone to drift. To measure the drift during the control of crawling insects on house walls, first trials were conducted. Independent of the wind direction, the measured drift directly in front of the treated area was very low. In the lateral distance to the treated area, the drift was lower with parallel than with orthogonal wind direction. In general, it is important to evaluate the equipment used to apply biocidal products.

Kurzbeschreibung: Reduzierung der Abdrift bei der Sprühapplikation/ Vernebelung von Bioziden - Ableitung von Risikominderungsmaßnahmen und Geräteanforderungen

Biozidprodukte und Pflanzenschutzmitteln gehören zur Gruppe der Pestizide und dienen dem Schutz von Mensch, Tier und Materialien gegen Schädlinge und Ungeziefer. Die meisten auf dem Markt befindlichen Biozidprodukte sind in Deutschland aufgrund von Übergangsbestimmungen im Rahmen der Biozid-Verordnung 528/2012 noch nicht bewertet worden, so dass geringe Kenntnisse darüber vorhanden sind, wie Biozidprodukte verwendet werden. Ziel dieser Studie war es Anwendungen mit hohem Abdriftpotential zu identifizieren und zu untersuchen. Es zeigte sich, dass die Bekämpfung des Eichenprozessionsspinners (EPS) mit Sprühgeräten und die Bekämpfung von fliegenden und kriechenden Insekten an Gebäuden mit einem Rückensprühgerät die Bereiche mit dem höchsten Abdriftpotential sind. Ergebnisse der Abdriftmessungen zeigen, dass bei allen Anwendungen die Abdrift exponentiell mit der Entfernung vom der behandelten Bereich abnahm. Darüber hinaus wurden die höchsten Abdriftwerte bei der Bekämpfung des ESP mit einer Sprühkanone am Waldrand, etwas niedrigere Abdriftwerte in der Allee und deutlich niedrigere Abdriftwerte an einem Einzelbaum gefunden. Bei der Verwendung eines Hubschraubers wurden um 50% geringe Abdrifteckwerte beobachtet, wenn eine Düse mit größeren Tropfen verwendet wurde. Diese ersten Ergebnisse zeigen, dass eine Abdrift in Nicht-Zielflächen wahrscheinlich ist. Es werden Möglichkeiten dargestellt, wie die Abdrift durch die Auswahl abdriftmindernder Technik reduziert werden kann. Um die Abdrift während der Bekämpfung von kriechenden Insekten an Hauswänden zu messen, wurden erste Tests durchgeführt. Unabhängig von der Windrichtung war die gemessene Abdrift direkt vor der behandelten Fläche sehr gering. In seitlicher Entfernung zur behandelten Fläche war die Abdrift bei paralleler Windrichtung geringer als bei orthogonaler Windrichtung. Im Allgemeinen ist es wichtig die Geräte näher zu betrachten, die zur Ausbringung von Bioziden verwendet werden.

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BAuA	German Federal Institute for Occupational Safety and Health
BPR	Biocidal Product Regulation
Bti	*Bacillus thuringiensis israelensis*
Btk	*Bacillus thuringiensis kurstaki*
DJI	Da-Jiang Innovations Science and Technology Co
ESD	Emission Scenario Document
JKI	Julius-Kühn Institute
LOD	Limit of Detection
OECD	Organisation for Economic Co-operation and Development
OPM	Oak processionary moth
RKI	Robert Koch-Institute
UAV	Unmanned Aerial Vehicle

Summary

Biocidal products protect humans, animals and materials against pests and vermin, such as insects, mice, rats, algae or bacteria. Even though biocidal and plant protection products are summarized under the broader term pesticides, both have their own product regulations. The biocidal product regulation 528/2012 (BPR) regulates biocidal products consistently within European Union, but most of the biocidal products have not been evaluated due to transitional regulations. In contrast to the equipment used for the application of plant protection products, the equipment used for the application of biocidal products is not regulated. Therefore, there are still knowledge gaps about the way in which biocidal products are used as well as what the effect of drift potential of these applications will be. This study was carried out to close these knowledge gaps. The aim of this work is

(1) to give an overview of the risk of the drift when using biocidal products;

(2) to identify applications and application techniques in which a direct environmental exposure to drift may occur;

(3) to measure drift values from experimental studies for the environmental exposure assessment and derivation of risk reduction measures and

(4) to derivate basic drift values from measured drift date.

Biocidal products are classified in 22 product-types and these product-types are again summarised in four main groups. The four main groups are "Disinfectants", "Preservatives", "Pest control" and "Other biocidal products". A comprehensive literature research showed, that a direct environmental exposure by drift is possible in five of these 22 product-types. All five biocidal products are sprayed with devices like cannon sprayers, helicopters, UAVs (unmanned aerial vehicle), knapsack sprayers, high-pressure sprayers, pump sprayers or similar devices. The area with the highest drift potential is the control of the oak processionary moth (OPM) with sprayers followed by the control of flying and crawling insects in the surrounding of buildings with a knapsack sprayer. To identify application areas and application techniques in which a direct environmental exposure by drift may occur, drift values were measured for the environmental exposure assessment and the derivation of risk reduction measures for these applications.

In the first part of these trials, the environmental exposure was quantified during the control of OPM. The first equipment evaluated was a cannon sprayer. Trials were conducted treating a solitary tree, an avenue and a forest edge. Additionally, a UAV was used for a solitary tree and a helicopter with two different nozzle types was used at an avenue. All these trials were based on the use of a guideline published by the Julius-Kühn Institute for the testing of plant protection equipment and especially for the measuring of direct drift when applying plant protection products outdoors. According to this guideline, the environmental exposure data as ground sediment with petri dishes at distances of 5, 10, 20, 30, 50, 75 m and, depending on the size of the measured area, 85 or 100 m from the treated area was recorded.

In the second part, the environmental exposure during the control of crawling insects on house walls with a 1 m foundation application was determined. Simulating a house wall, these trials were carried out with a knapsack sprayer at a 7.45 m-container. According to the Emission Scenario Document of the Organisation for Economic Co-operation and Development (OECD), the ground sediments were collected with petri dishes at 0.5, 1, 2 and 3 m in front of the container and at 1, 2 and 3 m lateral to the container.

All trials were conducted under realistic conditions. The liquid used was water mixed with the fluorescent dye pyranine. The applications were carried out at temperatures lower than 25 °C, wind speeds between 1 and 5 m s^{-1}, and a mean wind direction not exceeding 30° of the perpendicular of the movement direction of the sprayer. The amount of collected tracer dye pyranine was determined in a laboratory by fluorimetry. The 90th percentile of the ground sediment in percent of the application rate was used to evaluate the drift. The 90th percentile corresponds to a worst-case scenario and is used for the derivation of basic drift values for plant protection product equipment's.

The results show, that in all applications the drift decreased exponentially with the distance from the treated area. Using the cannon sprayer, the highest drift values were found at the forest edge. Slightly lower drift values were observed at the avenue and considerably lower drift values at the solitary tree. The differences of the drift values between the different equipment related set-ups were due to the different circumstances. The cannon sprayed the solitary tree from the windward side directly into the crown. At the avenue, the cannon sprayed also the spray liquid directly into the crowns from the windward side, but the gaps between the trees influenced the drift negatively and resulted in a higher drift than at the solitary tree. At the forest edge, the cannon sprayed the spray liquid also directly into the crowns but from the downwind side. It might be, that a part of the spray did not penetrate the crowns, but was sprayed aside the crowns and thus drifted away.

A further observation when using the cannon sprayer was the partly defoliation of the oak trees which was independently from the trial areas. The cannon sprayer generated a very high air velocity so that during the application, leafs and branches were torn from the trees. Caterpillars of OPM develop their burning hairs in the third larval stage. If a cannon sprayer will be used and old nests containing these hairs are present, it is possible that the high air velocity of the cannon sprayer distributes the hairs leading to possible human health risks.

The use of UAV is a very new application technique by aircraft. According to § 18 of the German Plant Protection Act the application of plant protection products with aircrafts is forbidden. For biocidal products, there are no such regulations. Therefore, the environment exposure was measured during the application using a UAV. The results show a maximum value of drift of almost 100% at 5 m distance, and it appears that the UAV had partially flown over the treatment area and sprayed the spray liquid directly into the collecting petri dishes. During the trial, it was not possible to control the UAV with GPS and other automated flight controls thus the UAV was manually controlled and the flight path was directly over the tree regardless of the wind direction. Because of these difficulties, the trial should be regarded as a preliminary test and the results should be interpreted carefully.

Two different nozzle types were used at the helicopter to examine the influence of this nozzles when creating basic drift values. The Airmix 110-05 nozzle is the standard nozzle for this kind of helicopter applications and the ID-120-05 POM is a nozzle with bigger droplets. The results show that using the ID-120-05 POM nozzle compared to the Airmix 110-05 nozzle, lower basic drift values of 50% could be achieved. Furthermore, using the helicopter with the ID-120-05 POM nozzle the drift was considerably lower than with the cannon sprayer. Other advantages of the helicopter compared to the cannon sprayer are an 18times lower liquid rate and a shorter application time. However, it necessary to be noted, that the verification of the efficacy was not the aim of this whole program. Whether a helicopter application with an application rate of 1.5 l per tree has the same efficacy as a cannon sprayer application should be elaborated in a separate trial program.

To calculate the drift when controlling crawling insects, a knapsack sprayer with flat fan nozzle was used. For that, the drift potential was measured in relation to two different wind directions. Regardless of the wind direction, the measured drift values directly in front of the treated area were very low and well below the default values of the OECD Emission Scenario Document. On the lateral side to the treated area, much higher drift values were found than in the front. Especially when wind comes in orthogonal, higher values were found than with parallel wind direction.

These first results regarding the drift potential from the application of biocidal products show that it is likely that biocidal products drift into non-target areas, leading to potential risks for non-target organisms. However, the results also show possibilities to reduce the drift by choosing the technology least prone to drift. In general, the results show the importance to evaluate the equipment that is used to apply biocidal products. Only if more knowledge regarding the drift potential of the equipment used is available, the risk of drift into non-target areas can be reduced as much as possible.

Until now, a test of equipment for the application of biocidal products has not been conducted. It would be important to develop a comparable regulatory framework as it is already in place for equipment used to apply plant protection products.

Zusammenfassung

Biozidprodukte schützen Mensch, Tier und Materialien vor Schädlingen und Ungeziefer wie Insekten, Mäusen, Ratten, Algen oder Bakterien. Auch wenn Biozidprodukte und Pflanzenschutzmittel zur Gruppe der Pestizide gehören, gelten für beide Produkte eigene Produktvorschriften. Die Biozid-Verordnung 528/2012 reguliert Biozidprodukte innerhalb der Europäischen Union einheitlich, aber die meisten Biozidprodukte sind aufgrund von Übergangsbestimmungen noch nicht bewertet worden. Anders als für Geräte zur Ausbringung von Pflanzenschutzmitteln sind Geräte der Ausbringung von Biozidprodukten nicht reguliert. Daher gibt es immer noch Wissenslücken, wie Biozidprodukte verwendet werden und welches Abdriftpotential Geräte zur Ausbringung von Biozidprodukten haben. Um diese Wissenslücken zu schließen, wurde diese vorliegende Arbeit durchgeführt. Ziel dieser Arbeit ist es,

(1) einen Überblick über das Abdriftrisiko bei der Anwendung von Biozidprodukten zu geben;

(2) Anwendungen und Anwendungstechniken, in denen eine direkte Umweltbelastung durch Abdrift auftreten kann, zu ermitteln;

(3) Abdriftwerte aus experimentellen Studien für die Umweltrisikobewertung und Risikominderungsmaßnahmen zu messen und

(4) Basiseckwerte aus gemessenen Abdriftwerten abzuleiten.

Biozidprodukte werden in 22 Produktarten unterteilt und diese Produktarten werden wiederrum in vier Hauptgruppen zusammengefasst. Die vier Hauptgruppen sind "Desinfektionsmittel", "Konservierungsmittel", "Schädlingsbekämpfung" und "Andere Biozidprodukte". Eine umfassende Literaturrecherche ergab, dass in fünf der 22 Produktarten eine direkte Umweltexposition durch Abdrift möglich ist. Diese fünf Produktarten werden mit Geräten wie Sprühkanonen, Hubschraubern, UAV (unbemanntes Fluggerät), Rückensprühgerät, Hochdruckspritzen, Pumpsprühgerät oder ähnlichen Geräten im Freiland angewendet. Der Bereich mit dem höchsten Abdriftpotential ist die Bekämpfung des Eichenprozessionsspinners (EPS) mit Sprühvorrichtungen, gefolgt von der Bekämpfung von fliegenden und kriechenden Insekten in der Umgebung von Gebäuden mit einem Rückensprühgerät. Um Anwendungsbereiche und -techniken zu identifizieren, in denen eine direkte Umweltexposition durch Abdrift auftreten kann, wurden Abdriftwerte aus experimentellen Studien für die Umweltrisikobewertung und die Ableitung von Risikominderungsmaßnahmen erfasst.

Im ersten Teilbereich dieser Versuche wurde die Umweltexposition während der EPS-Bekämpfung gemessen. Zunächst wurde die Umweltexposition bei der Anwendung einer Sprühkanone an einem Einzelbaum, an einer Allee und an einem Waldrand gemessen. Danach wurden ein UAV an einem Einzelbaum und ein Hubschrauber mit zwei verschiedenen Düsen an einer Allee eingesetzt. Bei all diesen Versuchen wurde die vom Julius-Kühn Institut erstellte Richtlinie für die Prüfung von Pflanzenschutzgeräten und insbesondere für die Messung der direkten Abdrift beim Ausbringen von Pflanzenschutzmitteln im Freien angewendet. Demnach wurde die Umweltexposition als Bodensediment mit Petrischalen in einer Entfernung von 5, 10, 20, 30, 50, 75 m und, in Abhängigkeit von der Größe der Messfläche, in 85 oder 100 m von der behandelten Fläche gemessen.

Im zweiten Teilbereich der Versuche wurde die Umweltexposition während der Bekämpfung von kriechenden Insekten an Hauswänden mit einer Fundamentbehandlung bis 1 m Höhe gemessen. Diese Versuche wurden mit einem Rückensprühgerät an einem 7,45 m langen Container durchgeführt. Gemäß der Annahme im Emission Scenario Document der Organisation für wirtschaftliche Zusammenarbeit und Entwicklung (OECD) wurde das Bodensediment mit

Petrischalen bei 0,5, 1, 2 und 3 m vor dem Container und bei 1, 2 und 3 m seitlich neben dem Container gemessen.

Alle Versuche dieser beiden Teilbereiche wurden unter realistischen Bedingungen durchgeführt. Die verwendete Sprühflüssigkeit wurde mit dem fluoreszierenden Farbstoff Pyranin mit einer Konzentration von 0,2% versetzt. Die Anwendungen wurden bei Temperaturen unter 25 °C, Windgeschwindigkeiten zwischen 1 und 5 m s^{-1} und Windrichtung von nicht größer als 30° Abweichung von der mittleren Windrichtung durchgeführt. Die Menge an gesammeltem Tracer-Farbstoff Pyranin wurde im Labor durch Fluorometrie bestimmt. Die Bewertung der Abdrift erfolgte mit dem 90. Perzentil des Bodensediments in Prozent der Auftragsmenge. Das 90. Perzentil entspricht einer Worst-Case-Szenario-Überlegung und wird zur Ableitung von Abdrifteckwerten für Geräte zur Ausbringung von Pflanzenschutzmitteln verwendet.

Die Ergebnisse zeigen, dass die Abdrift in allen Anwendungen exponentiell zur Entfernung vom behandelten Bereich abnahm. Bei der Verwendung einer Sprühkanone zur Bekämpfung von EPS wurden die höchsten Abdriftwerte am Waldrand gefunden, etwas niedrigere Abdriftwerte an der Allee und deutlich niedrigere Abdriftwerte am Einzelbaum. Die unterschiedlichen Abdriftwerte zwischen den Anwendungsbereichen können aufgrund der unterschiedlichen Gegebenheiten erklärt werden. Bei dem Einzelbaum wurde die Anwendung von der windzugewandten Seite durchgeführt, und die Sprühkanone sprühte die Spritzflüssigkeit direkt in die Krone. Bei der Anwendung an einer Allee sprühte die Sprühkanone die Spritzflüssigkeit auch von der windzugewandten Seite direkt in die Krone, aber die Abstände und Lücken zwischen den Bäumen könnten die Abdrift negativ beeinflusst haben und könnten zu einer höheren Abdrift als beim Einzelbaum geführt haben. Am Waldrand versprühte die Sprühkanone die Spritzflüssigkeit auch direkt in die Krone, jedoch von der windabgewandten Seite. Möglicherweise drang ein Teil der Spritzflüssigkeit nicht in die Krone ein, sondern wurde neben die Krone gesprüht und davongetragen.

Eine weitere Beobachtung beim Einsatz der Sprühkanone war die teilweise Entlaubung der Eichen unabhängig vom Anwendungsbereich. Die Sprühkanone erzeugte eine sehr hohe Luftgeschwindigkeit, so dass während der Anwendung Blätter und Äste von den Bäumen gerissen wurden. Raupen vom ESP entwickeln ihre Brennhaare im dritten Larvenstadium. Wenn die Sprühkanone an Bäumen mit älteren Nestern, die diese Brennhaare beinhalten, angewendet wird, ist es möglich, dass die hohe Luftgeschwindigkeit der Sprühkanone die Brennhaare weg transportieren und die menschliche Gesundheit schädigen kann.

Die Verwendung von UAV ist eine sehr neue Anwendungstechnik für die Ausbringung mit Luftfahrzeugen. Gemäß § 18 des deutschen Pflanzenschutzgesetzes ist die Ausbringung von Pflanzenschutzmitteln mit Luftfahrzeugen jedoch verboten. Für Biozidprodukte gibt es keine derartigen Vorschriften. Die Ergebnisse zeigten einen maximalen Abdriftwert von fast 100% bei 5 m Entfernung zur behandelten Fläche, und es scheint, dass das UAV zu weit über die behandelte Fläche geflogen ist und die Spritzflüssigkeit direkt in die Petrischalen gesprüht hatte. Zum Zeitpunkt des Versuchs war es technisch nicht möglich, das UAV mit GPS und anderen automatisierten Flugsteuerungen zu steuern, so dass das UAV manuell gesteuert wurde und der Flugweg unabhängig von der Windrichtung direkt über dem Baum war. Aufgrund dieser Schwierigkeiten sollten die Ergebnisse vorsichtig interpretiert werden.

Am Hubschrauber wurden zwei verschiedene Düsentypen verwendet, um den Einfluss der Düsen auf die Ableitung von Abdrifteckwerte zu untersuchen. Die Airmix 110-05 Düse ist eine Standarddüse für diese Art von Hubschrauberanwendung und die ID-120-05 POM ist eine Düse mit größeren Tröpfchen. Die Ergebnisse zeigen, dass bei Verwendung der ID-120-05 POM Düse um 50% geringere Abdrifteckwerte gegenüber der Airmix 110-05 Düse erreicht werden kann.

Darüber hinaus war mit der ID-120-05 POM Düse die Abdrift deutlich geringer als bei Verwendung der Sprühkanone. Weitere Vorteile des Hubschraubers gegenüber der Sprühkanone sind, dass die Flüssigkeitsrate 18-fach niedriger und die Anwendungszeit deutlich kürzer war. Es sollte jedoch angemerkt werden, dass Wirksamkeitsuntersuchungen nicht das Ziel dieser Studie waren. Ob eine Hubschrauberanwendung mit einer Ausbringmenge von 1,5 l pro Baum die gleiche Wirksamkeit wie eine Sprühkanone hat, sollte in einem separaten Versuch gemessen werden.

Zur Messung der Abdrift bei der Bekämpfung von kriechenden Insekten an einer Hauswand wurde eine Rückenspritze mit Flachstrahldüse eingesetzt. Zudem wurde das Abdriftpotential bei zwei verschiedenen Windrichtungen gemessen. Unabhängig von der Windrichtung waren die gemessenen Abdriftwerte vor dem Container sehr niedrig und deutlich unter den Standartwerten der OECD. Seitlich neben dem Container wurden weitaus höhere Abdriftwerte gefunden als vor dem Container. Vor allem bei orthogonaler Windrichtung wurden höhere Werte gefunden als bei paralleler Windrichtung.

Diese ersten Ergebnisse zum Abdriftpotential bei der Anwendung von Biozidprodukten zeigen, dass eine Abdrift der Produkte in Nicht-Zielflächen wahrscheinlich ist. Dies kann zu Risiken für Nicht-Zielorganismen führen. Die Ergebnisse zeigen aber auch Möglichkeiten, wie die Abdrift durch die Auswahl abdriftmindernder Technik reduziert werden kann. Im Allgemeinen zeigen die Ergebnisse wie wichtig es ist Geräte näher zu betrachten, die zur Ausbringung von Bioziden verwendet werden. Bislang ist dies nicht der Fall. Es wäre wichtig, dass für Geräte zur Ausbringung von Bioziden vergleichbare Regularien entwickelt werden, wie dies bereits für Geräte zur Ausbringung von Pflanzenschutzmitteln der Fall ist. Nur wenn das Abdriftpotential der Geräte bekannt ist, können die Risiken, die dadurch für die Umwelt entstehen, so weit wie möglich reduziert werden.

1 Introduction

Biocidal products belong, together with plant protection products, to the group of pesticides (EU 2009) and are used to protect humans, animals and materials against pests and vermin, such as insects, mice, rats, algae or bacteria. Due to the large action spectrum, biocidal products can negatively affect non-target organisms and therefore pose risks to the environment (EU 2012; Gartiser et al. 2012). For this reason, biocidal products are subject to an authorisation requirement according to the Biocidal Product Regulation 528/2012 (BPR) (EU 2012). Within this authorisation procedure, the (eco)toxicological properties, exposure and the effectiveness are evaluated. Even though biocidal products have a comparable purpose to plant protection products, the standards regarding machinery for their application are much lower than for plant protection products. For the application of plant protection products, articles 9 and 11 of the *Directive 2009/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides* (EU 2009) require low-drift equipment to be used during aerial spraying or especially in vertical crops. For biocidal products, there are no such requirements. Measurements of spray drift during the application of biocidal products have therefore not been conducted until now. Up to now, a lot of biocidal products on the market in Germany are still not authorised due to transitional regulations, so there is still a very little knowledge about the way in which biocidal products are used in the various product-types (EU 2014; REACH-CLP-Biozid 2017).

The aim of this work is:

(1) to give an overview of the risk of the drift when using biocidal products;

(2) to identify applications and application techniques in which a direct environmental exposure to drift may occur;

(3) to measure drift values in experimental studies for the environmental exposure assessment and risk reduction measures and

(4) to derivate basic drift values from measured drift values.

1.1 Biocidal product-types and their potential of a direct environment exposure by drift

The group of the potential target organisms of biocidal products is very large. Therefore, biocidal products are divided in 22 product-types and these product-types are summarised in four main groups. The four main groups are "Disinfectants", "Preservatives", "Pest control" and "Other biocidal products" (EU 2012). In the following, the 22 product-types are presented and the drift potential of the associated biocidal products is described.

Main group 1: Disinfectants

Disinfectants prevent the spread of infections by harmful microorganisms and make an important contribution to health protection.

<u>Product-type 1: Human hygiene.</u>

This product-type comprises products, which are used for human hygiene and mainly for skins and scalps disinfection (EU 2012). Products of this product-type are for example hand sanitiser or antimicrobial and antiseptic soaps (Gartiser & Jäger 2013), which are in direct contact to the skin and scalp (Uhlenbrock 2014). They can prevent nosocomial infections (infections acquired in clinics) and are used for prophylaxis in pandemics (VCI 2014). They will not be applied using methods with a high drift potential. Therefore, a direct environmental exposure to drift of these products can be ruled out.

Product-type 2: Disinfectants and algaecides not intended for direct application to humans or animals.

This product type comprises products, which are used for surface, textiles and furniture disinfection. These surfaces, textiles and furniture do not stand in direct contact to foods or feed. Usage areas comprise swimming pools, air conditionings, and walls and floors in private, public and industrial areas (EU 2012). In detail, one possible use of biocidal products from this product-type is the disinfection of work areas such as operating theatres in clinics or in medical practices, but also the disinfection of textiles. The Robert Koch-Institute (RKI) defines guidelines with detailed requirements on the hygiene of textiles like bed linen (RKI 2003). A direct environmental exposure by drift through this application can be ruled out. Another possible usage of biocidal products from this product-type is the control of green growth on paths, terraces and masonry in the outdoor area. For this application, a knapsack sprayer or a pump spray bottle is used (BAuA 2017e). Therefore, a direct environmental exposure by drift of this product-type is possible.

Product-type 3: Veterinary hygiene.

This product-type comprises products, which are used for materials and surface disinfection in the veterinary field. These are animal facilities or transportation vehicles for animals (EU 2012). The disinfection of animal facilities is often performed in pig and poultry farming. The application of disinfectant will be carried out by high-pressure cleaners (Raffael & van de Plassche 2011). An application by nebuliser or vaporization device is only possible in small and absolutely airtight spaces (Bodenschatz 2012). Therefore, a direct environmental exposure by drift can be ruled out for this type of application. However, one possible usage in this product-type is the disinfection of vehicles used for animal transport for protection against epidemics. High-pressure cleaners are used here, in order to prevent the disease from spreading (BMELV 2009). When the disinfection of vehicles used for animal transport is done in the outdoor area, a direct environmental exposure by drift of this product-type is possible.

Product-type 4: Food and feed area.

This product-type comprises products, which are used for surface, container, equipment, consumption utensils, and pipework disinfection. The products stand in direct contact with food and feed and are applied in the production, transport, storage or consumption of food or feed for humans and animals (EU 2012). One possible usage of biocidal products from this product-type is the disinfection of surfaces, dishes and working tools in professionally and private kitchens (VCI 2014). The application of disinfectants will be carried out by spray devices, wipes, lathers, dipping or vapour applications (Bodenschatz 2012). Because the products of this product-type are only used within buildings (Bodenschatz 2017), a direct environmental exposure by drift can be ruled out.

Product-type 5: Drinking water.

This product-type comprises products, which are used for drinking water disinfection for human and animals (EU 2012). Reprocessing of fresh water with the help of disinfectants is required and regulated by the European Drinking Water Ordinance (EU 1998) and the German Drinking Water Ordinance (BMJV 2001). Following § 11 of the German Drinking Water Ordinance, the disinfection can be carried out by chlorine dioxide solution, chlorine gas solution, sodium/calcium hypochlorite solution, chlorine and ozone (UBA 2015). The solutions are added in special dosing systems directly in the waterworks therefore, a direct environmental exposure by drift can be ruled out.

Main group 2: Preservatives

The second main group summarizes product-types that serve to preserve the quality of different products and to extend their service life.

<u>Product-type 6: Preservatives for products during storage.</u>

The products of this product-type protect manufactured products in containers against microbial deterioration to ensure their shelf life (EU 2012). The application of the products is in industrial processes and production (Müller & Bleck 2008). Therefore, a direct environmental exposure by drift can be ruled out.

<u>Product-type 7: Film preservatives.</u>

The products of this product-type protect surfaces against microbial deterioration or algal growth. Surfaces with fragile properties are paints, plastics, sealants, wall adhesives, binders, papers and art works (EU 2012). The application is predominantly in industrial production processes as a part of the product formulation (Müller & Bleck 2008). Therefore, a direct environmental exposure by drift can be ruled out.

<u>Product-type 8: Wood preservatives.</u>

The products of this product-type preserve wood and wood products by the control of wood-destroying or wood-disfiguring organisms, including insects (EU 2012). Also for wooden components that have to be protected from rain and moisture, such as trusses, the use of biocidal products may be required to protect them from wood-destroying organisms. If an infestation by harmful organisms has occurred in wooden components, for example, by wood-destroying insects or the real dry rot, they can be controlled with suitable biocidal products (VCI 2014). The application of wood preservative products can be used by industrial use or by in-situ application. By industrial use with a vacuum pressure impregnation, an environmental exposure can be ruled out. The manual in-situ application can be carried out by brushing and spraying. Therefore, a direct environmental exposure by drift of this product-type is possible.

<u>Product-type 9: Fibre, leather, rubber and polymerised materials preservatives.</u>

The products of this product-type protect fibrous or polymerised materials, such as leather, rubber or textile products by the control of microbiological deterioration (EU 2012). The application is predominantly done in industrial production processes (Müller & Bleck 2008). Therefore, a direct environmental exposure by drift can be ruled out.

<u>Product-type 10: Construction material preservatives.</u>

The products of this product-type protect masonry, composite materials, or other construction materials other than wood by the control of microorganisms and algae (EU 2012). Because the applications are closely related, some authors combine the products of the product-type 7 and 10 (Migné 2002; Gartiser et al. 2015). Products for the preventive or curative treatment of building materials can be applied by spraying (Migné 2002). Therefore, a direct environmental exposure by drift of this product-type is possible.

Product-type 11: Preservatives for liquid-cooling and processing systems.

The products of this product-type protect water or other liquids used in cooling and processing systems by the control of harmful organisms such as microbes, algae and mussels (EU 2012). This also includes products that are used in petroleum production against the development of sulphur bacteria. The application is predominantly in industrial production processes (Müller & Bleck 2008). Therefore, a direct environmental exposure by drift during the application can be ruled out.

Product-type 12: Slimicides.

The products of this product-type prevent slime growth on materials, equipment and structures, used in industrial processes, e.g. on wood and paper pulp or porous sand strata in oil extraction (EU 2012). One application example is the use of biocidal products in paper production. By the use of biocidal products, large amounts of fresh water can be saved annually and corrosion of technical equipment caused by microbial slime can be prevented (VCI 2014). The application is predominantly in industrial production processes (Müller & Bleck 2008). Therefore, a direct environmental exposure by drift can be ruled out.

Product-type 13: Working or cutting fluid preservatives.

The products of this product-type control microbial deterioration in fluids used for working or cutting metal, glass or other materials (EU 2012). One product-type are cooling lubricants, which are used in chip-forming and non-cutting forming for cooling (water), lubricating (oil) and removing of metal. The application is predominantly in industrial production processes (Müller & Bleck 2008). Therefore, a direct environmental exposure by drift can be ruled out.

Main group 3: Pest control

Main group 3 summarizes biocidal products used to control various pests.

Product-type 14: Rodenticides.

The products of this product-type control mice, rats or other rodents, by means other than repulsion or attraction (EU 2012). Rodents can affect human health and can transmit diseases (VCI 2014). In general, rodenticides are used as solid baits. The fumigant aluminium phosphide is used against Norway rats and voles by qualified persons outside (BAuA 2017c). As gasses and the other products are not liquid, a direct environmental exposure by drift can be ruled out.

Product-type 15: Avicides.

The products of this product-type control birds, by means other than repulsion or attraction (EU 2012). And according to § 4 of the regulation of the authorization of biocidal products and other chemical legislation related to biocidal products and biocidal active substances (EU 2012), the authorization of biocidal products of this product-type is forbidden in Germany (BMJV 2006). For this reason, the product-type was not further evaluated in the project.

Product-type 16: Molluscicides, vermicides and products to control other invertebrates.

The products of this product-type control molluscs, worms and invertebrates not covered by other product-types, by means other than repulsion or attraction (EU 2012). In Germany, there are no registered biocidal molluscicides. Products, which contain molluscicides and are no plant protection products cannot be sold in Germany (BAuA 2017b). A direct environmental exposure by drift can therefore be ruled out.

Product-type 17: Piscicides.

The products of this product-type control fish, by means other than repulsion or attraction (EU 2012). According to § 4 of the regulation of the authorization of biocidal products and other chemical legislation related to biocidal products and biocidal active substances (EU 2012), the authorization of biocidal products of this product-type is forbidden in Germany (BMJV 2006) For this reason, the product-type was not further evaluated in the project.

Product-type 18: Insecticides, acaricides and products to control other arthropods.

The products of this product-type control arthropods (e.g. insects, arachnids and crustaceans), by means other than repulsion or attraction (EU 2012). Applications of these products in the outdoor area are the control of flying and crawling insects on house walls, control of wasps, control of oak processionary moths (OPM) and the control of mosquitoes (OECD 2008; Becker 2017; Freise 2017; Loch 2017). A direct environmental exposure by drift of this product-type is possible for different applications, therefore these application possibilities will be described in more detail.

Control of flying and crawling insects on house walls: To control flying insects the whole wall should be sprayed. To control crawling insects it is possible to only spray a stripe around the house (foundations application) with a contact insecticides or to spray a combination of a foundation and a ground application (OECD 2008).

Control of wasps: To control wasps on house walls, biocidal products can be sprayed directly in wasp nests or can be sprayed around the nest.

Control of oak processionary moths: Currently, products with the substances *Bacillus thuringiensis kurstaki* (Btk) and Margosa extract are available and must only be applied by a qualified person. The products can be applied by different methods. It is possible to use a cannon sprayer, a motor sprayer from a lift or a helicopter (BAuA 2017a). A new application technique is the application via UAV (unmanned aerial vehicle).

Control of mosquitoes: Products with the active substance *Bacillus thuringiensis israelensis* (Bti) as ice granules are available. Based on the size of the granules, a direct environmental exposure by drift can be ruled out.

Product-type 19: Repellents and attractants.

The products of this product-type control harmful organisms by repelling or attracting, including those that are used for human or veterinary hygiene either directly on the skin or indirectly in the environment of humans or animals (EU 2012). For example, products containing the active substance diethyltoluamide were authorised for non-professional use for the spray application on the skin (BAuA 2017d). To protect horses against horseflies, repellents are sprayed directly on the horse skin, therefore a direct environmental exposure by drift of this product-type is possible.

Product-type 20: Control of other vertebrates.

The products of this product-type control vertebrates other than those already covered by the other product-types of this main group, by means other than repulsion or attraction (EU 2012). According to § 4 of the regulation of the authorization of biocidal products and other chemical legislation related to biocidal products and biocidal active substances (EU 2012), the authorization of biocidal products of this product-type is forbidden in Germany (BMJV 2006). For this reason, the product-type was not further evaluated in the project.

Main group 4: Other biocidal products

Product-type 21: Antifouling products.

The products of this product-type control the growth and settlement of fouling organisms on vessels, aquaculture equipment or other structures used in water (EU 2012). Antifouling products can be applied with brushes, rollers or airless sprayers. A direct environmental exposure by drift cannot be ruled out.

Product-type 22: Embalming and taxidermist fluids.

The products of this product-type disinfect and preserve human or animal corpses, or parts thereof (EU 2012). They are used in closed buildings, therefore a direct environmental exposure by drift can be ruled out.

1.2 Equipment for application of biocidal products with high drift potential

The description of all 22 product-types shows that a direct environmental exposure by drift is possible in five product-types. Table 1 shows a list of applications in which a direct environmental exposure to drift may occur. It is noticeable that in all applications spray devices will used so that an environmental exposure is possible. The product-types will be sprayed with a cannon sprayer, helicopter, UAV, knapsack sprayer, high-pressure sprayer, pump sprayer or with a similar device.

Table 1: List of trial areas in which a direct environmental exposure to drift may occur (Kanne-Schludde et al. 2018).

Product-Type	Application	Application technique
18	Control of oak processionary moth	Cannon sprayer, motor sprayer, UAV or helicopter
18	Control of flying and crawling insects in the surrounding of buildings	Knapsack sprayer
3	Disinfection of vehicles used for animal transport	Knapsack sprayer, high-pressure cleaner
02/10	Control of green growth on paths, terraces and masonry	Knapsack sprayer, pump spray bottle
18	Control of mosquitos	Knapsack sprayer
07/10	Facade protection	Airless-Sprayer
18	Control of wasps	Knapsack sprayer, dusting devices, aerosol spray can
19	Repellents for the control of horsefly	Pump spray bottle

The application with the highest drift potential is the control of OPM with spray devices. The cannon sprayer is the most frequently used device for the control of OPM. It produces very high air velocity to transport the spray solution into high trees up to over 30 m (HARDI 2010). To reach this height, the device is equipped with a strong blower and produces large spray clouds (TOPPS-Prowadis 2014). Therefore, in plant protection application, cannon sprayers should only be used at large solitary trees, in viticulture in steep slopes (TOPPS-Prowadis 2014) or in Christmas tree growing (Landwirtschaftskammer-NRW 2012). In biocidal application, trials by Goff et al. (2014) with a cannon sprayer at a solitary tree showed that the used tracer was found up to 50 m away from the treatment area. A further device to control OPM is a knapsack and hand-guided motor sprayer. The droplet spectrum is between 50 and 150 µm (Sommer 2006). Droplets smaller than 100 µm have a high drift potential (Miller 2003; Franke et al. 2010). A direct environmental exposure to drift using this sprayer is possible. This environmental exposure will be greater if the motor sprayer is used from a lift to apply in high trees for example. A helicopter or a UAV can also be used for the control of OPM. According to § 18 Plant Protection Act, the drift by the spraying of pesticides with aircrafts can have significant adverse effects to human health. So the spraying with aircrafts is only allowed when compared to other application techniques there are clear advantages according to lower environmental exposure (EU 2009). A permit should only be granted for the control of harmful organisms in viticulture in steep slopes or in the crown area of forests (BMJV 2012). However, this application method is not regulated in the same manner under the BPR (EU 2012) and according to the product information of the biocidal products to be used, an aircraft is an authorised application method (BAuA 2017a). According to § 13 Air Traffic Regulation (LuftVO), the discarding or discharging of objects or other substances from aircraft is forbidden, but this does not apply to ballast in the form of water (BMJV 2015). Therefore, an application of biocidal product using an aircraft or an unmanned aerial vehicle is admissible.

The second and the subsequent ranks in the priority list are applications using knapsack sprayers and similar devices. They cover inter alia: the control of flying and crawling insects, the disinfection of vehicles used for animal transport, the control of green growth on paths, terraces and masonry, the control of mosquitos and the control of wasps. Trials with plant protection products show that the factors affecting drift from knapsack sprayers are not much different from normal field sprayers. However, for knapsack sprayers, the drift potential can be slightly higher, because it is difficult to work with a constant spray pressure, sprayer height and spray angle. In addition, the applications will be done forward or upwards, therefore a direct environment exposure by drift is possible and higher than in tractor spray applications (Franke et al. 2010). The same also applies to the application technique with airless-sprayer to protect facades and to the application technique with high-pressure device to disinfect vehicles used for animal transporters (Koch et al. 2004; BMELV 2009). It should also be noted, that overspray is likely to happen during the spraying with these techniques. Overspray is the effect when the product reaches the target area and then rebounds back in the atmosphere due to the high impact speed. Where spraying is used and depending on the application conditions, the overspray can mount up to approx. 30% of the material input (EC 2007). Therefore, airless sprayers produce lower environment expositions than spray applications (Koch et al. 2004; Bleck & Müller 2008).

At the end of the priority list, application techniques like aerosol spray cans, dusting devices and pump spray bottles to control wasps and to repel horseflies are listed. Although the droplet size is smaller than 100 µm, these devices are listed at the end, because these devices are used in a very small extent (Schneider et al. 2008; Franke et al. 2010).

1.3 Available guideline to measure direct drift

A guideline to measure the drift of biocidal products has not been produced yet. However, two documents with requirements and information about the measurement of drift do exist. The Julius Kühn-Institute (JKI) has issued a guideline for the testing of plant protection equipment and especially for the measuring of direct drift when applying plant protection products outdoors (JKI 2013). In addition, the Organisation for Economic Co-operation and Development (OECD) define default values for control flying and crawling insects on house walls in their Emission Scenario Document (ESD). The JKI guideline and the OECD document will be illustrated here.

The JKI guideline includes requirements and information about the testing of plant protection equipment and especially for the measuring of direct drift when applying plant protection products outdoors (JKI 2013). For the measurements of direct drift, no plant protection product is used, but a fluorescent tracer. Therefore, it is possible to transfer this method directly to the testing of biocidal devices outdoors.

Direct drift is that part of the amount of active ingredient applied which is borne beyond the treated area due to atmospheric conditions (Stephenson et al. 2006; Hilz & Vermeer 2013). That part of the active ingredient, which evaporates and leaches is not considered as direct drift (Hilz & Vermeer 2013; JKI 2013). As the drift is measured in outdoor settings, several experimental parameters cannot be influenced and might not be stable during the tests. However, the JKI guideline defines limits for several parameters. If the parameters remain within these limits, it has been shown that the results of drift measurements of different experimental institutes are comparable. The trial area includes a treated area and a measuring area. The treated area is the area where the application will take place and shall be at least 50 m long and 20 m wide. However, this is only valid for surface application. For a solitary tree application, the treated area has not to be defined explicitly. The measuring area is the area, which is located in wind direction next to the treated area and where the active ingredient is measured as drift.

The used spray liquid is water mixed with a tracer in a sufficient and verifiable concentration. Afterwards, the trial area is treated with this liquid. Each treatment/trial shall be repeated at least three times and during this, the weather data shall be constantly recorded. The data to be recorded are wind direction, wind speed, air temperature and relative humidity. The weather station to record these parameters shall stand in the centre axis behind the measuring area in 1 m above the height of the culture but at least in 2 m height from the ground. Valid trials must be conducted at air temperature not exceeding 25 °C, average wind speed between 1 m s^{-1} and 5 m s^{-1} and average wind direction not exceeding more than 30° from the line rectangular to the direction of travel.

To measure the direct drift as ground sediments, passive drift collectors like petri dishes are placed on the ground. The arrangement of the petri dishes depends upon the task of the trial. It is possible to place the petri dishes 1, 2, 3, 4, 5, 7.5, 10, 15, 20, 30, 40, 50, 75 and 100 m away from the treated area. However, at least five distances shall be selected. Ten petri dishes shall be placed with a spacing of 1 m for each distance. The starting point for fixing the distance from the treated area is half of a nozzle spacing from the outermost nozzle in field crops and half a row width from the midst of the outermost row in orchards, viticulture and hop-growing. The amount of collected products is measured depending on the kind of tracer by fluorometric or atomic absorption spectrometric.

To measure the drift during the application of biocidal products against OPM, the above mentioned guideline was transferred with minimal adaption (see chapter 2.1.1-2.1.3).

To transfer the trial setting to the context of devices for application of biocidal products against insects on house walls, further adaptions were necessary. To define a default setting, the Emission Scenario Document (ESD) of the Organisation for Economic Co-operation and Development (OECD) for insecticides, acaricides and products to control other arthropods for household and professional uses was used (OECD 2008). In this document, the scenarios for outdoor applications around the buildings were reported with two sub-scenarios: the spray application on walls against flying insects and the spray application on grounds and foundations against crawling insects. The simulated house is 17.5 m long, 7.5 m wide and the height is 2.5 m. For the application against flying insects, the entire walls are treated up to 2.5 m and for the application for crawling insects, it is considered that the treatment of foundation up to 0.5 m height together with a treatment of a 0.5 m wide band of ground is sufficient to protect the house from infestation. From an environmental point of view, the fractions emitted to the ground during outdoor foundation spray application due to deposition and run-off are not negligible. The deposition fraction is measured 50 cm away from the treated area. For application against crawling insects, the same emission factors for deposition and run-off will be used as for the application against flying insects. However, these emission factors will be supplemented by the fraction emitted to ground during spray application in the adjacent untreated zone. This fraction will be measured 1 m away from the treated area (OECD 2008).

1.4 Transfer of existing basic drift values

Basic drift values for plant protection products were developed taking into account the guideline for the testing of plant protection equipment and especially for measuring direct drift when applying plant protection products outdoors (JKI 2013). Table 2 shows basic drift values for different application areas of plant protection products depending on different distances for household and professional uses that were developed with the JKI guideline (Rautmann et al. 2001; JKI 2016).

A table like this with different treated areas and different distances is not available for biocidal applications. Because of this data lack for drift during the treatment of house walls, the fraction emitted to ground during outdoor ground spray application in the adjacent untreated zone by drift ($F_{spray,untreated\ ground}$) was defined by OECD (2008) based on drift values for agricultural sprayers derived using the above mentioned JKI guideline. However, OECD (2008) states that "if more realistic data are available concerning the potential for exposure to the untreated zone (e.g. experimental or measured data etc.) then these may be used in place of the default". Such direct transfer of data from devices used for the application of plant protection products is not easy because several parameters are not comparable (e.g. treated area, vegetation height). A comparison of the application types and types of treated areas in Table 2 with Table 1 shows that the main applications of biocidal products with a high drift potential are not covered by the available basic drift values. Therefore, it is essential to carry out experimental investigations for the derivation of basic values for the spray application of biocidal products.

Table 2: Basic drift values for simple applications as ground sediment in percent of the application rate calculated based on the 90th percentile (excerpt from Federal Gazette, as of 27 March 2006, (JKI 2016)).

Distance (m)	Field crops	Orcharding		Viticulture	Hop Growing	Field Crops	Vegetable Gardening, Ornamental Crops, Soft Fruit (for portable sprayers)			Railway Tracks	Houses and allotment garden				
		early	late			application rate > 900 l ha-1	height < 50 cm	height < 50 cm with spray shield	height > 50 cm		Bed, height < 50 cm	Tree, late	Viticulture, early, Tree, early, height < 2 m, Soft Fruit and Ornamental Crops, height > 50 cm	Tree, early, height > 2 m	Viticulture, late Vegetable and Soft Fruit late height > 50 cm
1	2.77					4.44	2.77	0.040			0.42				
3		29.20	15.73	8.02	19.33			0.011	8.02	0.019		3.53	13.52	38.09	0.72
5	0.57	19.89	8.41	3.62	11.57	0.18	0.57	0.010	3.62	0.014	0.020	0.78	2.93	9.58	0.19
10	0.29	11.81	3.60	1.23	5.77	0.05	0.29		1.23	0.010	0.005	0.10	0.37	1.47	0.03
15	0.20	5.55	1.81	0.65	3.84	0.02	0.20		0.65	0.008	0.002	0.03	0.11	0.49	0.01
20	0.15	2.77	1.09	0.42	1.79	0.012	0.15		0.42	0.007	0.001	0.01	0.05	0.23	0.005
30	0.10	1.04	0.54	0.22	0.56	0.005	0.10		0.22	0.006					
40	0.07	0.52	0.32	0.14	0.25	0.003	0.07		0.14						
50	0.06	0.30	0.22	0.10	0.13	0.002	0.06		0.10	0.004					

Table 3: Default values in percent for emission factors during outdoor spray perimeter treatment against flying and crawling insects (OECD 2008).

Variable/parameter	Symbol	Default value flying insects	Default value crawling insects
Fraction emitted to air during outdoor spray application	$F_{spray,air}$	0.00	0.00
Fraction emitted to soil during outdoor foundation spray application due to deposition	$F_{spray,deposition}$	10.0	10.0
Fraction emitted to soil during outdoor foundation spray application due to run-off	$F_{spray,run-off}$	20.0	20.0
Fraction directly emitted to soil during outdoor ground spray application	$F_{spray,soil}$		99.0
Fraction emitted to soil during outdoor ground spray application in the adjacent untreated zone	$F_{spray,untreated\ soil}$		0.42
Fraction emitted to soil due to foundation wash-off by rainfall	$F_{spray,wash-off}$	50.0	50.0

2 Material and Method

The priority list in Table 1 shows the applications and application techniques where the risk of a direct environmental exposure to drift is high. Within this study, drift values for the environmental exposure assessment and risk reduction measures were collected for these applications and application techniques. The drift potential of the application techniques using a cannon sprayer, UAV and helicopter were measured simulating the control of OPM in a solitary tree, an avenue or a forest edge. In the second part, the drift potential of the control of crawling insects on house walls with a knapsack sprayer was measured.

2.1 Experimental investigations for the derivation of drift values

All trials were carried out in practice and the used spray liquid was water mixed with the fluorescent dye pyranine. Pyranine is a green-yellow powdered sodium salt (trade name: Pyranine 120%, Colour Index: Solvent Green 7) and is used, for example, for highlighters or for dyeing dishwashing detergents (Herbst & Wygoda 2006). All trials were repeated 10 times at each area and weather data were recorded during the applications. The combined weather sensor WENTO-IND (Lambrecht, Göttingen, Germany) was used and measured air temperature, wind speed, wind direction and relative humidity with an ample rate of 1 s^{-1}. The applications were evaluated at temperatures lower than 25 °C, wind speeds between 1 and 5 m s^{-1} and wind direction not exceeding 30° of deviation from the mean wind direction (JKI 2013). To measure the direct drift as ground sediments, petri dishes as passive drift collectors were placed on the ground on the downwind side. The petri dishes had a diameter of 145 mm and were put on wooden slats or ground spikes. The orientation of the petri dishes was dependent on the treated area and treated object. In addition, petri dishes were set up to determine the zero or blank value outside the measuring area. Five minutes after spraying, the petri dishes were closed, were brought to a place protected from light and were taken to the laboratory for extraction and quantification of the tracers. In addition, tank samples were taken during the trials in order to check the application rate and if the tracer concentration was stable throughout the application.

In the following, the application areas and the application techniques, which were used to measure the direct drift, will be described in more detail in the special sectors.

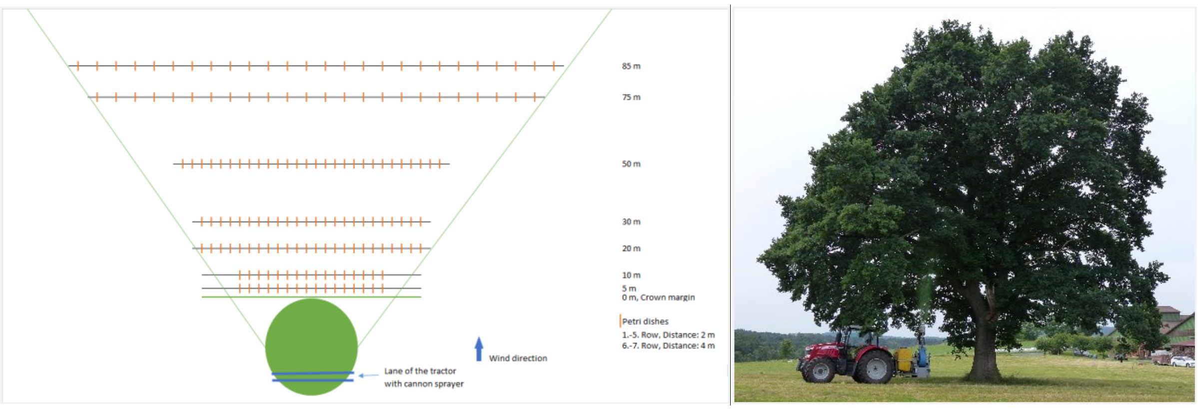
2.1.1 Cannon sprayer to control OPM at trees

The cannon sprayer is one of the most used techniques in the control of OPM. The field trials were carried out using a tractor-mounted cannon sprayer KWH B 612 (KWH Holland BV, Rhenen, Nederland). 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 pipe were used. Working speed was about 1.5 km h^{-1}, 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 practical applications as performed by the contractor. The used trial areas were a solitary tree, an avenue and a forest edge.

Experimental parameters and trial area: "solitary tree"

As described above, the trial area included a treated area and a measuring area. The treated area in this trial was a solitary tree, which was located in Langelsheim (51°57'22.9"N, 10°17'11.5"E), Lower Saxony, Germany. The length of the solitary tree was 23 m, the width was 22.50 m and the height was approx. 20 m, so the totalizing projection area was 517.5 m^2. A 0.5% pyranine concentration was used as spray liquid. The application time was 5:20 min and the application rate per tree was 46 l. This corresponds to a liquid rate of 890 l ha^{-1}. The lane of the tractor was at the windward side close to the tree trunk and the cannon sprayed the liquid directly into the crown. The measuring area was oriented to the mean wind direction of the solitary tree. Petri dishes as collectors were placed on the ground surface at known downwind distances from the treated area. The distance from the crown margin was 5, 10, 20, 30, 50, 75, and 85 m. Deviating from the JKI-guideline, it was not possible to fulfil the 100 m distance and a different number of petri dishes per distance was used. 16 petri dishes were used for the 5 and 10 m distance, 24 petri dishes were used for the 20, 30 and 75 m distance, 28 petri dishes were used for the 50 m distance and 32 petri dishes were used for the 85 m distance. The adaption of the setting was necessary to catch the whole drift cloud as ground sediment with this orientation. The petri dishes were placed on ground spike and stood in intervals of 2 m on the 5 to the 50 m distance and in intervals of 4 m on the 75 and the 85 m distance (Figure 1).

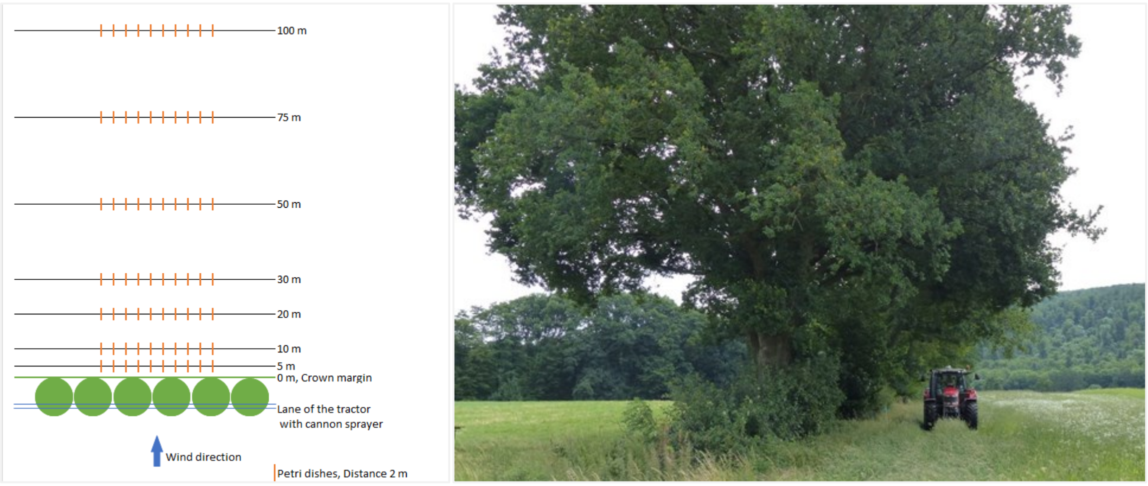
Figure 1: Schematic figure of the treated area and the measuring area at drift trials with a cannon sprayer at a solitary tree (left) and a tractor during the application (right).



Experimental parameters and trial area: "avenue"

The avenue was a single row of oaks in the location Langelsheim (51°57'09.7"N 10°16'14.2"E) in Lower Saxony, Germany. The length of the avenue was 125 m, the width was 23.5 m and the height was approx. 20 m, so the totalizing projection area was 2937.5 m^2. The application time was 10:30 min and the application rate per tree was 10 l. This corresponds to a liquid rate of 317 l ha^{-1}. A 0.2% pyranine concentration was used as spray liquid. During the application, the tractor drove at the windward side close to the avenue, treated the avenue two times and sprayed the liquid into the crown. The sprayer was not equipped with a gap detection system. The difference between the measuring area "solitary tree" and "avenue" is that at a solitary tree, it is necessary to catch the whole drift cloud and at an avenue, it is enough to catch a representative sector of the drift. Therefore, the width of the measuring area at an avenue was 18 m with 10 petri dishes per distance. The petri dishes were placed on wooden slats at intervals of 2 m. The distances from the crown margin were 5, 10, 20, 30, 50, 75 and 100 m.

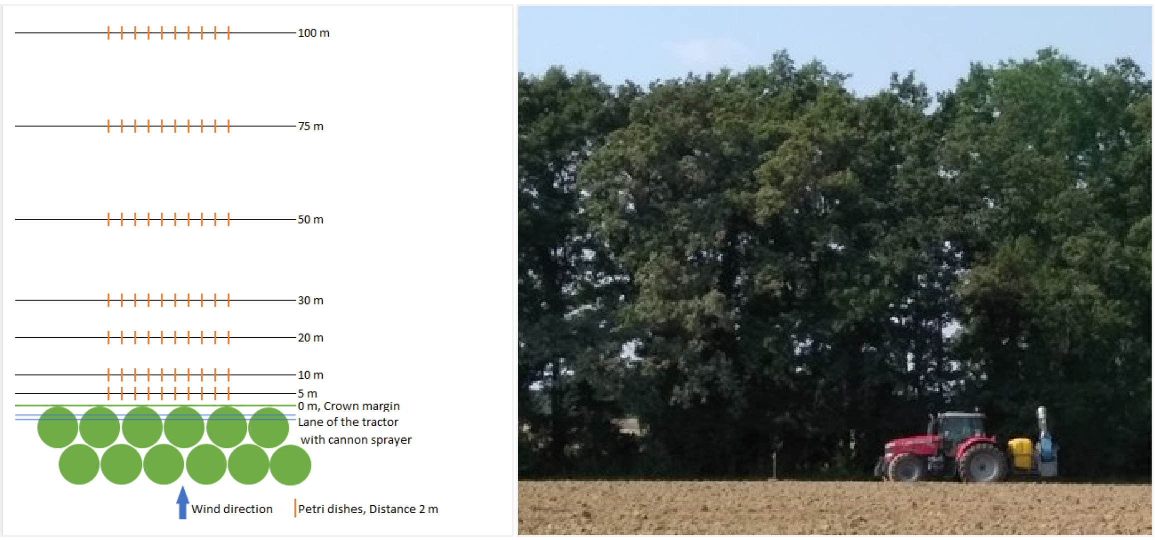
Figure 2: Schematic figure of the treated area and the measuring area at drift trials with a cannon sprayer at an avenue (left) and tractor during the application (right).



Experimental parameters and trial area: "forest edge"

The forest edge was located in Meine (52°21'31.3"N, 10°36'18.9"E) in Lower Saxony, Germany. The forest edge was treated at a length of 60 m. For the later following calculation of the ground sediment, a width of 30 m was taken, so that the totalizing projection area was 1800 m^2. The application time was 5 min and the application rate per tree was 5 l. This corresponds to a liquid rate of 241 l ha^{-1}. A 0.2% pyranine concentration was used as spray liquid. The main difference to the trial area "avenue" is that the tractor lane was on the downwind side and the cannon sprayed the liquid into the crown against the wind direction. The reason for this is that the trial area was a forest edge and it was not possible to drive through the forest, so the tractor lane was in front of the forest. The layout of the measuring area is identical to the measuring area in the avenue. The distances from the crown margin were 5, 10, 20, 30, 50, 75 and 100 m, where 10 petri dishes each were placed a wooden slats at intervals of 2 m.

Figure 3: Schematic figure of the treated area and the measuring area at drift trials with a cannon sprayer at a forest edge and a real figure of a tractor during the application.



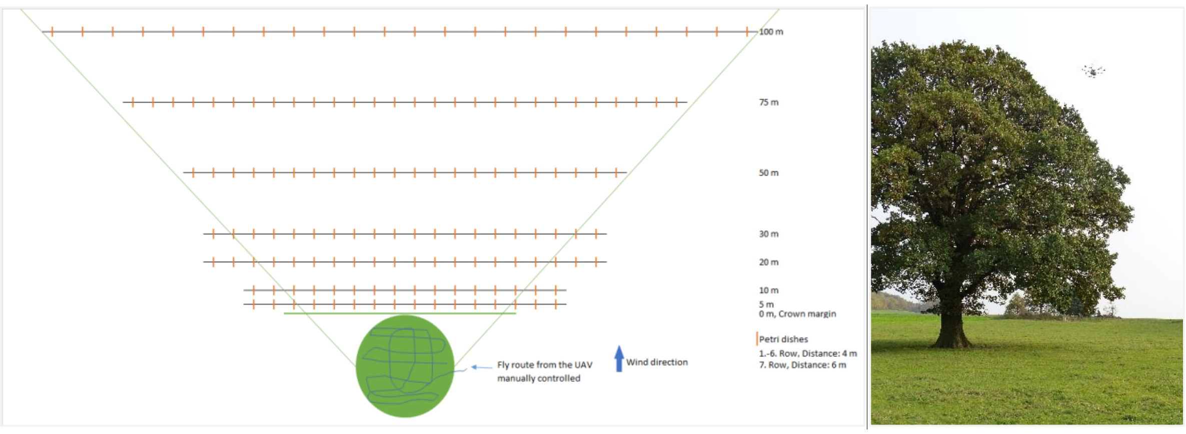
2.1.2 UAV to control OPM at a solitary tree

The used unmanned aerial vehicle was the Agras MG-1 from DJI (Shenzhen, China). This UAV has eight rotors and under four rotor arms, the spray system equipped with Airmix 110-05 nozzles was installed. In the centre of the UAV under the technical units, a tank was built-in with a volume of 10 l. The flow rate was 6.3 l min^{-1} and the nozzle pressure was 2 bar. These device settings correspond to the settings in real applications as performed by the contractor.

Experimental parameters and trial area: "solitary tree"

The trial area for the UAV application was similar to the trial area for the cannon sprayer application. However, differences were in the application method and in the orientation of the measuring area. The solitary tree for the UAV application was the same solitary tree as for the cannon sprayer application (Langelsheim: 51°57'22.9"N, 10°17'11.5"E, Lower Saxony, Germany), with the totalizing projection area of 517.5 m^2. The application time was based on the application rate of 10 l per tree. This corresponds to a liquid rate of 193 l ha^{-1}. A 0.5% pyranine concentration was also used as spray liquid. During the cannon sprayer application, the lane of the tractor was on the windward side of the tree, during the UVA application the UAV flew directly above the tree and sprayed the liquid into the crown. At this time, it was not possible to fly the UAV controlled by GPS and other automated flight controllers, so that the UAV was manually controlled and the flight path was independent of the wind direction directly above the tree. The main wind direction was different for the UAV application compared to the cannon sprayer application. The measuring area in this direction was longer and therefore, it was possible to measure the ground sediment at 100 m distance. This was an advantage because the analysis of the cannon sprayer application had shown that it would have been better to extend the measuring area in order to catch the whole drift cloud. The petri dishes at 5 m to 75 m distance stood in intervals of 4 m and the petri dishes at 100 m distance stood in an interval of 6 m. The number of petri dishes was also modified compared to the cannon sprayer trial. Sixteen petri dishes were used for the 5 and 10 m distance, 20 petri dishes were used for the 20 and 30 m distance, 22 petri dishes were used for the 50 m distance, 28 petri dishes were used for the 75 m distance and 24 were used for the 100 m distance.

Figure 4: Schematic figure of the treated area and the measuring area at drift trials with a UAV at a solitary tree (left) and a UAV during the application (right).



2.1.3 Helicopter to control OPM at an avenue

A helicopter contractor, who is specialised in the control of OPM in oak trees, did the applications with a helicopter. The provided helicopter was a Eurocopter of the type AS350 "Ecureuil" with a mounted simplex spray system. The sprayer boom had a total length of 10 m with 68 nozzles. The working speed was 35 km h^{-1} and the nozzle pressure was 2 bar. These device settings correspond to settings in real applications.

Experimental parameters and trial area: “avenue“

The trial area for the helicopter application was the same that was used for the cannon sprayer application. The application time was 8 s and the application rate per tree was 1.5 l. This corresponds to a liquid rate of 40 l ha^{-1}. A 0.2% pyranine concentration was used as spray liquid. Because the avenue consisted of a single oak row, the helicopter flew in the centre above the oak row and sprayed the liquid only with the sprayer boom section on the windward side. The boom section was 5 m long and had 34 nozzles. The layout of the measured area for the helicopter applications was identical to the layout for the cannon sprayer application. Except that in these trials, it was decided to measure the drift up to 85 m, instead of 100 m because of the influence of the trees at the end of the measuring area. The influence of the trees at the end of the measuring area was detected after the analyses of the petri dishes from the cannon sprayer application. The helicopter application was repeated 10 times with the Airmix 110-05 nozzles and five times with the ID-120-05 POM nozzles to find out whether different nozzles lead to different drift values.

Figure 5: Schematic figure of the treated area and the measuring area at drift trials with a helicopter at an avenue (left) and a helicopter at the avenue application (right).

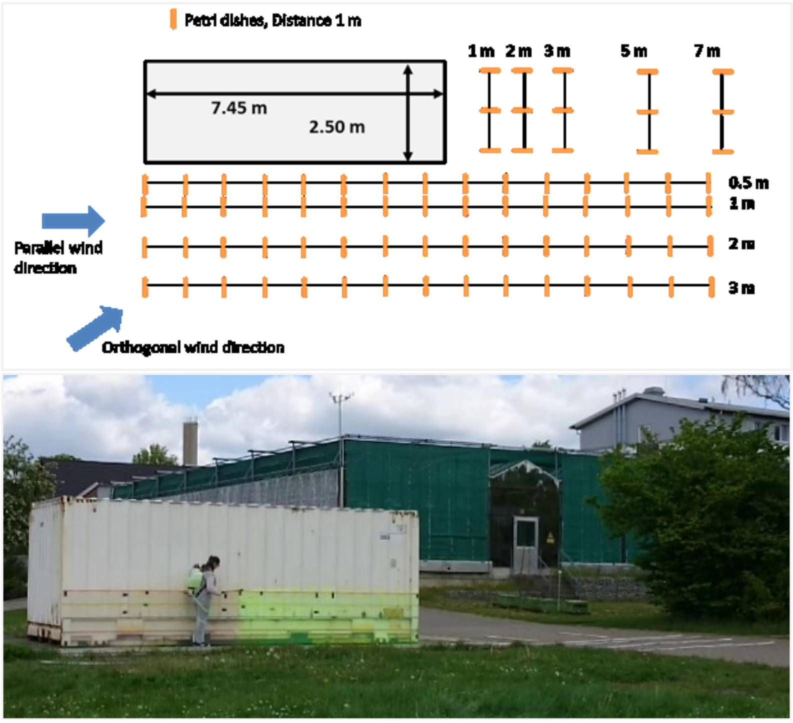
2.1.4 Knapsack sprayer to control crawling insects on house walls

The knapsack sprayer is one of the mostly used techniques to apply insecticides, acaricides and other biocides against arthropods for household and professional uses at house walls. The trials were carried out using the knapsack sprayer Chapin ProSeries 61800 (Chapin International Inc, Batavia, New York, USA). The tank had a capacity of 15 l. The fan nozzle Lurmark 04F80 with a flow rate of 1.17 l min^{-1} and a nozzle pressure of 1.45 bar was used. To carry out the trials with a stable nozzle pressure, a constant flow valve (Chapin 6-8501 21 PSI) was utilised.

Experimental parameters and trial area: house wall

A container was taken to simulate a house wall, because the building has to stand in wind direction to be able to measure a drift. The container was 7.45 m long and the surface was covered with plexiglas panes to simulate the house wall structure. For the foundation application, a 1 m stripe was treated. Other application heights will be a part of a follow-up project. However, a part of this project was to measure the influence of wind direction on direct drift. Therefore, the direct drift was collected at orthogonal wind direction and parallel wind direction to the treated area (Figure 6). The application time was 1:10 min and the amount of spray liquid was 1.26 l for the 7.45 m wall (1611 l ha^{-1}). A 0.2% pyranine concentration was used as spray liquid. During the application, the user moved backwards against the wind. The petri dishes were places on wooden slates at intervals of 1 m. 15 petri dishes per distance stood in front of the container. The distance from the wall was 0.5, 1, 2 and 3 m. Three petri dishes per distance stood lateral to the container. The distance from the wall was 1, 2, 3, 5 and 7 m (Figure 6). Therefore, it was possible to catch the whole spray drift as ground sediment. This trial was repeated 3 times at each of the two wind directions.

Figure 6: Schematic figure of the treated area and the measuring area at drift trials with a knapsack sprayer at a container (left) and a practical application of the knapsack sprayer (right)



2.2 Laboratory analysis

At first, dilution solutions were made from a stock solution. For the analyses, a 0.2% or a 0.5% stock solution depending on the used pyranine concentration was diluted in distilled water. Then, the tank samples were diluted 1:1000 with distilled water and were compared with the stock solution to determine the accurate spraying concentration. A calibration curve, with dilutions of 1:100.000, 1:50.000, 1:10.000, 1:5.000, 1:1.000 and 1:500 originated on the stock solution was created. The calibration curve was used to establish the limit of detection and to calculate the amount of spray deposit in the petri dishes.

In order to calculate the amount of tracer, which was collected in the petri dishes, 40 ml distilled water were filled into the treatment petri dishes and into the blank value petri dishes. This washing water should dissolve the collected pyranine. All petri dishes were placed on an orbital shaker table (Edmund Buhler, Shaker-SM 25, Germany) with constant shaking at 65 rpm for 10 min. Subsequently, the pyranine concentration in the washing water was measured by fluorometry. The Fluorometer SFM 25 (Kontron Instruments, France) at the excitation wavelength of 401 nm and emission wavelength of 503 nm was used to measure the pyranine concentration of the trial areas “solitary tree”, “avenue” and “forest edge”. The QFX Fluorometer (DeNovix, Wilmington, USA) at the excitation wavelength of 375 nm and emission wavelength from 435 to 485 nm (UV range) was used to measure the pyranine concentration of the trial area “container”. The reason for the two measurement methods was an improvement of the laboratory equipment during the study. Whereas the QFX Fluorometer is more sensitive and reproducible than the Fluorometer SFM 25, but this will not deteriorate the results.

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:

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

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

where *AR* is the application rate [l ha^{-1}], $Q_{nozzles}$ is the liquid flow of all used 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:

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

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

where β_{dep} is the spray drift deposit [µg cm^{-2}]; ρ_{smpl} is the fluorimeter reading of the sample [-]; ρ_{calib} is the fluorimeter reading of the diluted tank sample [-]; ρ_{blk} is the fluorimeter reading of the blank collector [-]; V_{dist} is the volume of distilled water [ml]; c_{calib} is the concentration of the diluted tank sample [mg l^{-1}] dependent of the dilution (for example 1:100000); 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 [µg ml^{-1}].

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

$$\beta_{dep\%} = \frac{\beta_{dep}}{TR} * 100 \quad (3)$$

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

2.3 Statistical analysis

The weather conditions during the application were measured with a cycle time of 1 s^{-1}. To analyse this database on validity of the conditions and for the calculation of means and standard deviations, Microsoft Excel and 'stat' package of Rstudio were used.

It is possible to present the measured results as a surface distribution over the whole measuring area or as direct drift values. For the surface distribution of the ground sediment over the whole measuring area, the 50th percentile (median) of the ground sediment in percent of application rate of each distance in each trial was used, because the amount of 10 repetitions values per distance in the line was too small to use the 90th percentile. The 90th percentile of the ground sediment in percent of application rate was used for the evaluation of the drift results. The 90th percentiles demonstrate a worst-case scenario, which is used for the derivation of basic drift values for plant protection products. According to Ganzelmeier et al. (1995), the 90th percentile is calculated from all individual values of all trials available per distance. This approach was followed for the calculation of the direct drift at the trial areas "avenue" and "forest edge". For the trial area "solitary tree", the maximum drift values per distance were used. The aim was to catch the whole drift cloud to find out the maximum drift scenario. For the determination of basic drift values, an exponential regression (best fit) was used and the basic drift values for each distance were calculated by the regression function.

For the calculation of the direct drift at the trial area container, the measured pyranine concentration was very low in the washing water of the petri dishes over all distances from the treated area. Therefore, it is necessary to establish a systematic process with an analytical method acceptable for its intended purpose. The limit of detection (LOD) is an important performance limit in method validation. This limit is used to describe the smallest concentration of an analyte that can be reliably measured by an analytical procedure and is estimated from the calibration curves according to DIN 32465 (DIN 2008) at a probability of 95%.

The maximum value was used to calculate the direct drift, because the measuring area lateral to the container with three collectors per distance. This number was too small to calculate the 90th percentile. To simulate the surface distribution of the ground sediment, the maximum values were used also.

3 Results

3.1 Drift values of a cannon sprayer application to control OPM

Meteorological conditions during the application

The meteorological conditions during the applications were mostly in line with the JKI guideline (JKI 2013). During the trials, the mean wind speed ranged between 2.34 m s^{-1} to 3.63 m s^{-1}, the mean air temperature ranged from 16.4 °C to 20.2 °C and lay under the critical value of 25 °C. The mean relative air humidity ranged from 65% to 73.7% during all measurements. Eight measurements were valid during the application at a solitary tree, nine measurements were valid during the application at an avenue and seven measurements were valid during the application at a forest edge. Mean meteorological conditions during the application of each trial area are shown in Table 4. Some measurements were excluded since the deviation from ideal wind direction exceeded 30° or lay outside the guideline limitation for the mean wind speed of 1 m s^{-1} to 5 m s^{-1}.

Table 4: Mean values of meteorological conditions during the cannon sprayer application at the trial areas "solitary tree", "avenue" and "forest edge" (± SD).

Parameters	Solitary tree		Avenue		Forest edge	
Temperature (°C)	20.2	± 0.80	20.2	± 0.85	16.4	± 1.04
Relative humidity (%)	65.0	± 1.47	68.6	± 2.19	73.7	± 4.22
Wind speed (m s^{-1})	2.34	± 0.62	3.22	± 0.56	3.63	± 1.03
Wind direction (°) in relation to the ideal direction	10.1	± 13.5	-17.7	± 10.6	4.56	± 19.5
Valid measurements	8		9		7	

Surface distribution of the ground sediment

The surface distributions of the ground sediment in percent of the application rate based on the 50th percentile for the cannon sprayer at the forest edge and at the avenue are presented in Figure 7. Different colours represent decreasing drift values. Over the measurement area, the drift decreased constantly with increasing horizontal distance in both trial areas, "forest edge" and "avenue". At the forest edge, it is striking that the drift values first increase until 5 m and then decrease depending on the distance to the forest edge. At the avenue, the drift constantly decreased with increasing horizontal distance. The surface distribution for the cannon sprayer application at the solitary tree based on maximum values is shown in Figure 8. The difference between the measuring area at the solitary tree on the one hand and avenue and forest edge on the other hand is that the ratio of the treated area to the measuring area is higher for the solitary tree than for the other trial areas. The measuring area at the solitary tree is supposed to catch the whole drift while the measuring areas at the avenue and the forest edge only represent samples of the drift clouds. The surface distribution of the solitary tree is decreasing with increasing horizontal distance. However, the drift decreased on the right side faster than on the left side. Some collectors on the right side were below LOD at 85 m. This distribution shows that the collectors collected a great part of the drift, but not the whole drift.

Figure 7: Surface distribution of the ground sediment in percent of the application rate at the cannon sprayer application at forest edge (left) and to the avenue (right) based on 50th percentile.

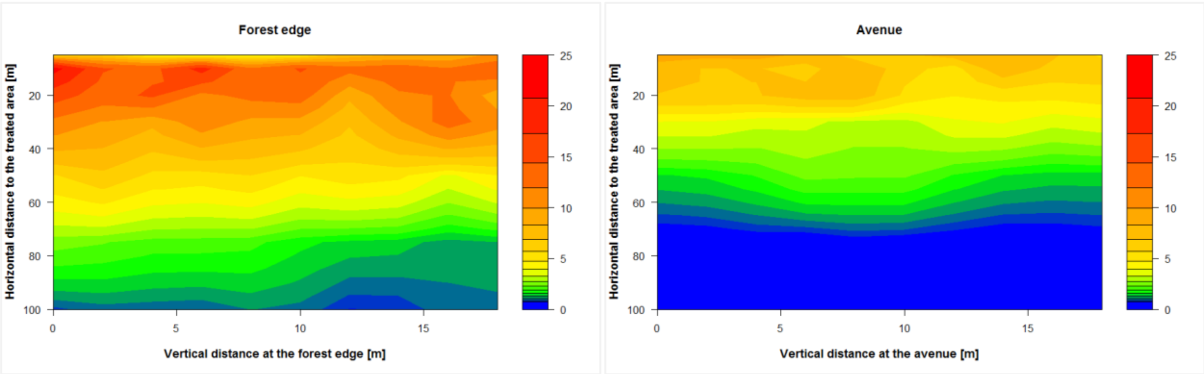
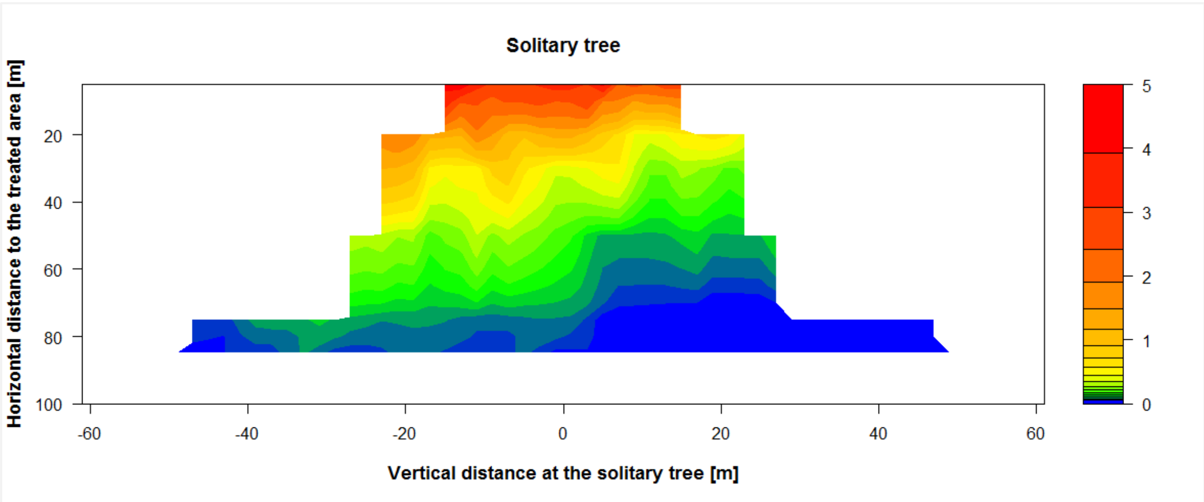


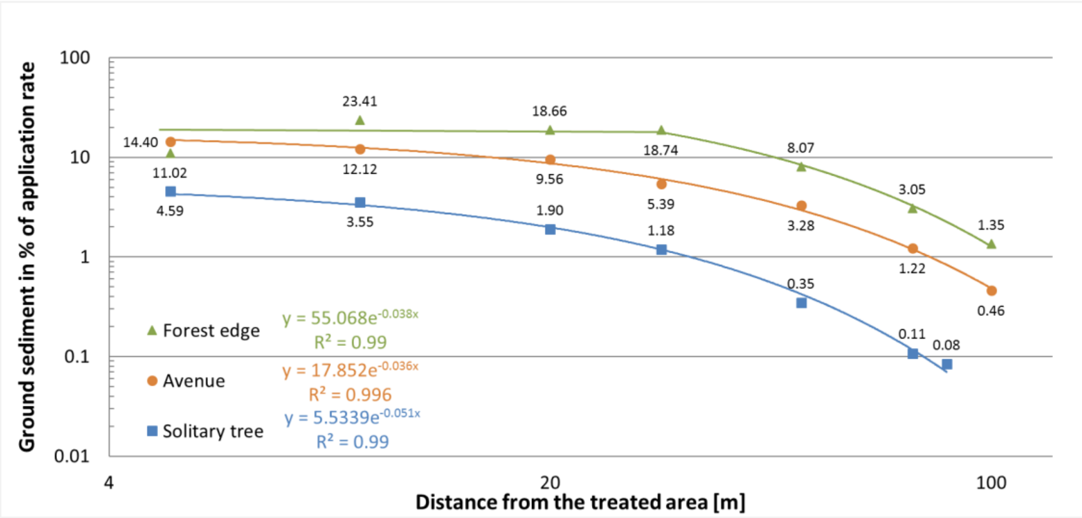
Figure 8: Surface distribution of the ground sediment in percent of the application rate at the cannon sprayer application at a solitary tree based on maximum values.



Measured drift values and basic drift values

The measured drift values as ground sediment in percent of application rate per distance are shown in Figure 9. The measured drift values for the forest edge and the avenue are based on the 90th percentile and for the solitary tree on maximum values. At the trial area "forest edge" a drift value of 11% and at the trial area "avenue", a drift value of 14.4% were observed at 5 m. At the trial area "solitary tree" the drift value was 4.59% at the same distance and significant under the drift values at the forest edge and at the avenue. At the forest edge, the drift value increased to 23.41% at 10 m. Up to 30 m, the drift value remained on the same level. Further, the drift value decreased so that a drift value of 1.35% was observed at 100 m. At the trial area "avenue", no increasing of drift values was monitored. In contrast, the drift values constantly decreased with increasing distance from the treated area. At 100 m, a drift value of 0.69% was noted. Despite the use the maximum measured drift values at the trial area "solitary tree", the drift values were significantly below the drift values (90th percentiles) from both other trial areas, "forest edge" and "avenue", at all distances from the treated area. At 5 m, the drift value was 4.59% and constantly decreased with increasing distance from the treated area to 0.08% at 85 m.

Figure 9: Measured drift values in percent of the application rate at the cannon sprayer application dependent to the distance to the treated area (Forest edge and avenue based on 90th percentile; solitary tree based on maximum values).



The regression lines shows a good correlation for the measured ground sediment. Therefore, the basic drift values were derived from the measured drift values using the exponential regression equation in Figure 9. The basic drift values are shown in Table 5. Due to the reason that at the trial area "forest edge" the measured drift values increased at 5 m and were stable up to 30 m, the maximum value of this distance range was used as a basic drift value at the distances up to 30 m. At the other distances and at the trial areas "avenue" and "solitary tree", the basic drift values were derived from the individual exponential regression equation due to their decreasing measured drift values at increasing distances.

Table 5: Basic drift values derived from the measured drift values in percent of the application rate at the cannon sprayer application dependent to the distance from the treated area based on 90th percentile at forest edge and avenue and based on maximum values at solitary tree.

Distance from the treated area [m]	Forest edge $y = 55.068e^{-0.038x}$	Avenue $y = 17.852e^{-0.036x}$	Solitary tree $y = 5.5339e^{-0.051x}$
5	23.41 *	14.91	4.29
10	23.41 *	12.45	3.32
20	23.41 *	8.69	2.00
30	17.61	6.06	1.20
50	8.24	2.95	0.43
75	3.19	1.20	0.12
85			0.07
100	1.23	0.49	

* Maximum value in the distance range 5 to 20 m of the 90th percentile 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.

3.2 Drift values of a UAV application to control OPM at a solitary tree

Meteorological conditions during the application

The meteorological conditions during the UAV application were very inconsistent. Only six of ten measurements were valid (Table 6). At these six measurements, the mean air temperature was 19.1 °C and lay under the JKI critical value of 25 °C. The mean relative humidity was 71.8% and the mean wind speed was 2.6 m s^{-1}. The mean wind direction was with 14.7° under the ideal wind direction but inside the required range of 30°.

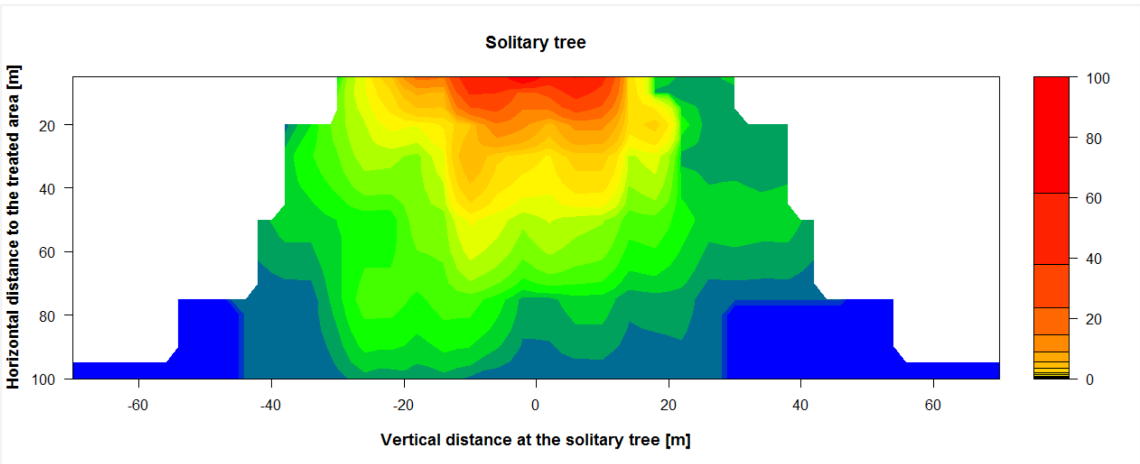
Table 6: Mean values of meteorological conditions during the UAV application at a solitary tree (± SD)

Parameters	Solitary tree	
Temperature (°C)	19.1	± 0.63
Relative humidity (%)	71.8	± 2.81
Wind speed (m s^{-1})	2.6	± 0.63
Wind direction (°) in relation to the ideal direction	-14.7	± 10.1
Valid measurements	6	

Surface distribution of the ground sediment

For the UAV application and the cannon sprayer application, the treated area was the same, but the measuring area at the UVA application was wider. Thus, it was possible to catch almost the whole drift (Figure 10). Different colours represent decreasing drift values with increasing horizontal distance. At 75 m and 100 m, in some collectors no tracer was detected. That shows, that it was a good approach to design the layout of the measurement area wider compared to the application with a cannon sprayer. In addition, it was good to catch the whole drift and not only a section because the wind direction changed during the trials and results for only a section of the measuring area would have led to a misinterpretation of the direct drift.

Figure 10: Surface distribution of the ground sediment in percent of the application rate at the UAV application at a solitary tree based on maximum values.

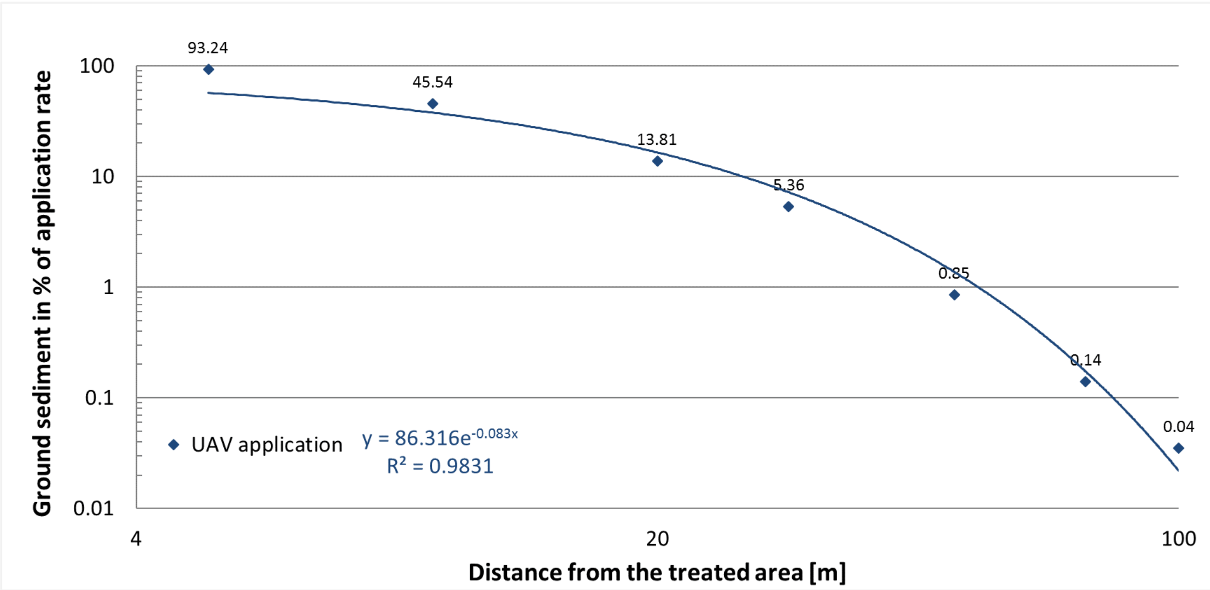


Measured drift values

The maximum values of the ground sediment in percent of the application rate per distance are displayed in Figure 11. At this application method, the drift values also decrease with increasing distance from the treated area. However, at 5 m behind the tree crown, the drift value was very high. The maximum value was almost 100% of the application rate. Behind this mark, the drift values decreased quickly. Therefore, at 75 m only 0.14% were observed and at 100 m only 0.04% of the application rate was observed.

Because the application with the UAV application was only an initial testing which is not an established method, no basic drift values were calculated from the measured drift values.

Figure 11: Measured drift values in percent of the application rate at the UAV application dependent on the distance to the treated area "solitary tree" based on maximum values.



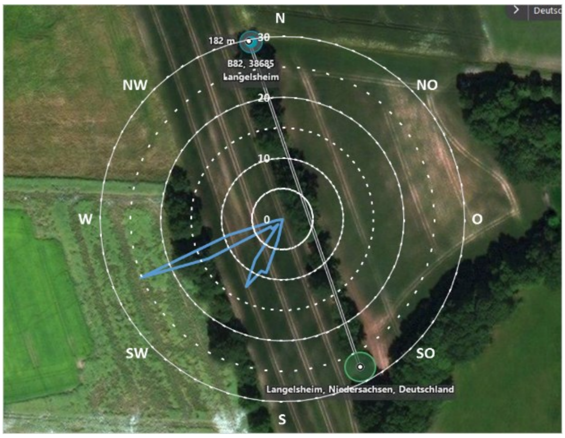
3.3 Drift values of a helicopter application to control OPM at an avenue

Meteorological conditions during the application

The meteorological conditions during the helicopter application at an avenue were very constant. All 15 measurement, 10 measurements with the Airmix 110-05 nozzle and five measurements with the ID-120-05 POM nozzle, were valid. However, the analysis of the collectors showed deviations in one measurement with the ID-120-05 POM nozzle. For this reason, this measurement was excluded. The mean values of meteorological conditions during the application of the 14 measurement are shown in Table 7. The mean air temperature was 19.9 °C and the mean relative humidity was 45.5%. The mean wind speed was 3.3 m s^{-1} and lay between the critical values from 1 m s^{-1} to 5 m s^{-1}. The wind direction transmitter of the weather station was based on southwest. The main wind direction was west-southwest and sometimes south-southwest. During the measurement, the wind direction differed only 5 °. The wind rose shows the avenue and the frequency distribution of the wind direction (Table 7).

Table 7: Mean values of meteorological conditions during the helicopter application at the avenue (± SD) and the wind rose as a frequency distribution of the wind direction.

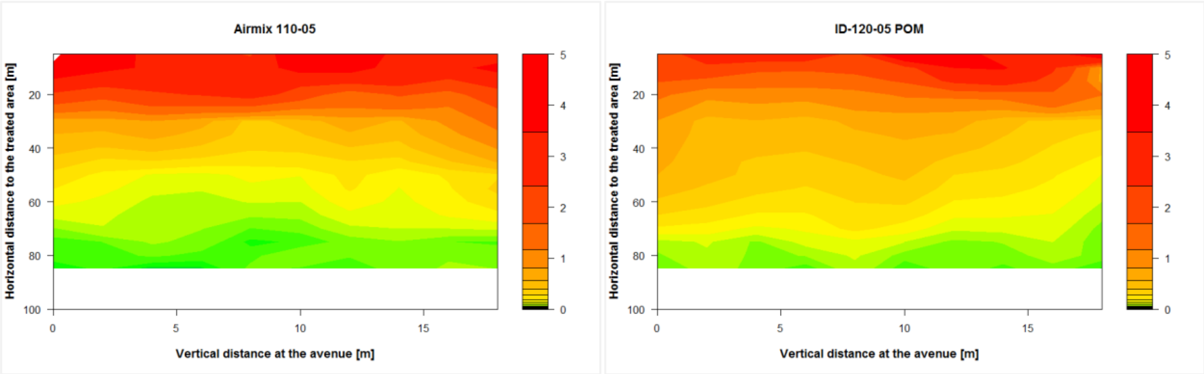
Parameters	Avenue	
Temperature (°C)	19.9	± 1.58
Relative humidity (%)	45.5	± 5.50
Wind speed (m s^{-1})	3.3	± 0.96
Wind direction (°) in relation to the ideal direction	5.0	± 21.4
Valid measurements	14	



Surface distribution of the ground sediment

The surface distribution of the ground sediment in percent of the application rate at the helicopter application with the Airmix 110-05 nozzle and with the ID-120-05 POM nozzle are shown in Figure 12. Different colours represent decreasing drift values with increasing horizontal distance. One difference between the drift distributions of the two nozzles is noticeable. Using the ID-120-05 POM nozzle, the drift decreases slightly slower on the left side than on the right side. That is in contrast to the using of the Airmix 110-05 nozzles. The drift decreases relatively constant in the horizontal distance. These results confirm that it is correct to measure the drift in a sample of the whole area prone to drift and that it is not necessary to catch the whole drift over the whole length of the avenue.

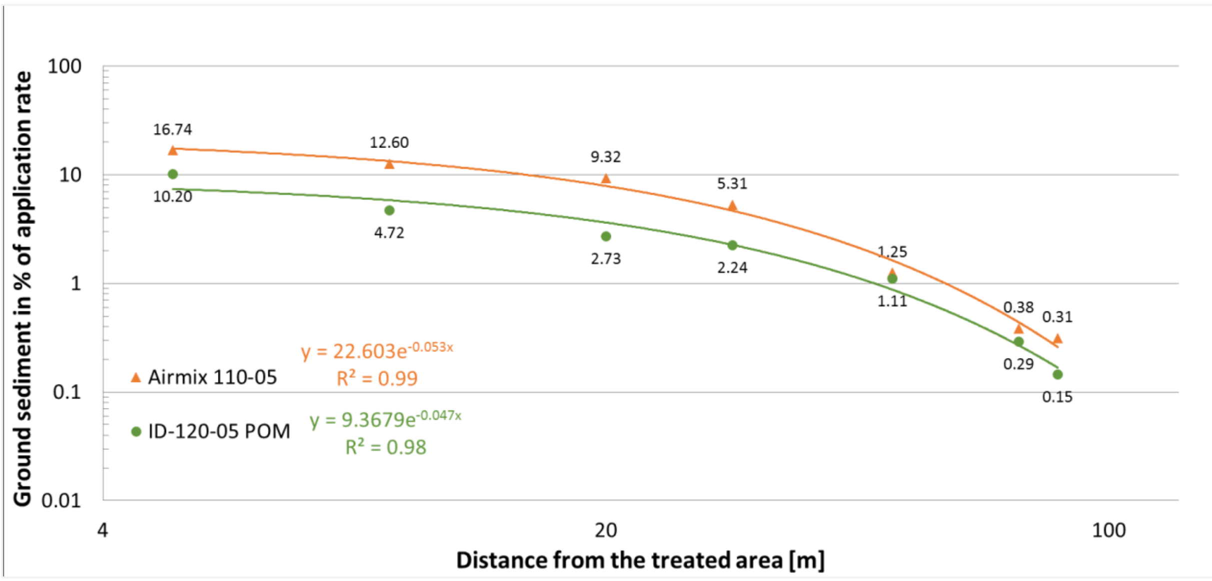
Figure 12: Surface distribution of the ground sediment in percent of the application rate at the helicopter application with the Airmix 110-05 nozzle (left) and with the ID-120-05 POM nozzle (right) based on the 50th percentile.



Measured drift values and basic drift values

The measured drift values in percent of the application rate at the helicopter application are shown in Figure 13. Two nozzles were tested and the drift value of both nozzles decreased with increasing distance from the treated area. Differences in the drift values of the two nozzles were observed. Over the whole distance, the drift values was significant lower using the ID-120-05 POM nozzle than using the Airmix 110-05 nozzle. At 5 m, the drift value was 16.74% using the Airmix 110-05 nozzles and 10.2% using the ID-102-05 POM nozzle. At 10 m and 20 m, the drift values were 3times higher and at 30 m, the drift value was more than twice as high. Beyond these distances, the drift values approached each other and the differences were low. However, at 85 m, the drift value was again twice as high using the Airmix 110-05 nozzle than using the ID-120-05 POM nozzle.

Figure 13: Measured drift values in percent of the application rate at the helicopter application dependent to the distance to the treated area "avenue" based on 90th percentile.



The coefficient of determination of the correlation between the measured ground sediment and the distance from the treated area was 0.99 using the Airmix 110-05 nozzle and 0.98 using the ID-120-05 POM nozzle. Due to their good correlation, it is possible to derive the basic drift values from the measured drift values using the exponential regression equation in Figure 13. The basic drift values are shown in Table 8. As well as for the measured drift values, the basic drift values using the ID-120-05 POM nozzle lay considerably below the basic drift values using the Airmix 110-05 nozzle.

Table 8: Basic drift values derived from the measured drift values in percent of the application rate at the helicopter application with two different nozzles dependent to the distance from the treated area "avenue" based on 90th percentile.

Distance from the treated area [m]	Helicopter with Airmix 110-05 $y = 22.603e^{-0.052x}$	Helicopter with ID-120-05 POM $y = 9.3679e^{-0.047x}$
5	17.34	7.41
10	13.30	5.85
20	7.83	3.66
30	4.61	2.29
50	1.60	0.89
75	0.42	0.28
85	0.25	0.17

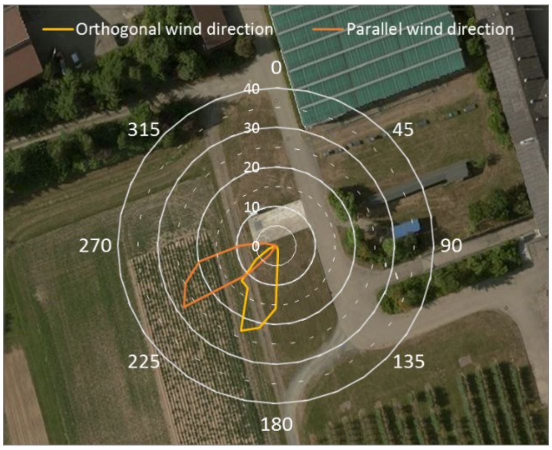
3.4 Drift values of a knapsack sprayer application to control crawling insects on house walls

Meteorological conditions during the application

The meteorological conditions during the 6 trials with the knapsack sprayer at a container were very constant. The mean air temperature was 9.25 °C and the mean relative humidity was 55.3%. The mean wind speed was 2.09 m s-1 and lay between the critical values from 1 m s^{-1} to 5 m s^{-1}. The main wind direction was 229° with a deviation of 29.3°. This is a very high deviation and the analysis of the wind direction has shown, that during 3 trials, the wind came from South-South-West and during the other 3 trials, the wind came from West-South-West. Therefore, the drift potential was evaluated depending on the wind direction. In the following, the conditions will be called as orthogonal wind direction (South-South-West) and parallel wind direction (West-South-West). More drift affected parameters, like wind direction and wind speed, will be tested in a follow-up project. The described tests are only initial tests.

Table 9: Mean values of meteorological conditions during the knapsack sprayer application (± SD) and the wind rose as a frequency distribution of the orthogonal wind direction and parallel wind direction.

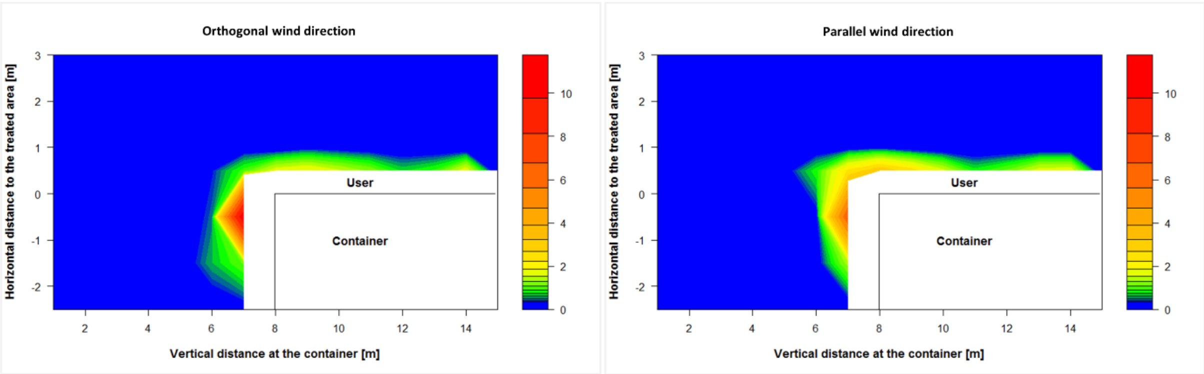
Parameters	Container	
Temperature [°C]	9.25	± 0.51
Relative humidity [%]	55.3	± 1.47
Wind speed [m s^{-1}]	2.09	± 0.40
Wind direction [°]	229	± 29.3
Valid measurements	6	



Surface distribution of the ground sediment

The surface distributions of the ground sediment based on maximum values with the knapsack sprayer application are shown in Figure 14. Different colours represent decreasing drift values with increasing distance to the treated area. The left figure shows the distribution of the ground sediment at the orthogonal wind direction and the right figure shows the distribution of ground sediment at parallel wind direction. The drift decreased constantly with increasing distance at both wind directions. Directly in front of the container, the ground sediment is very similar between the two wind directions. Lateral to the container and with a laterally offset, there are differences. During the South-South-West conditions, the wind orthogonally met the front of the container on the application side. In this case, ground sediment values lateral to the application area were high. During the West-South-West conditions, the wind blew parallel to the application area; ground sediment was low lateral to the application area but was high in a laterally offset in front of the container than during orthogonal wind direction.

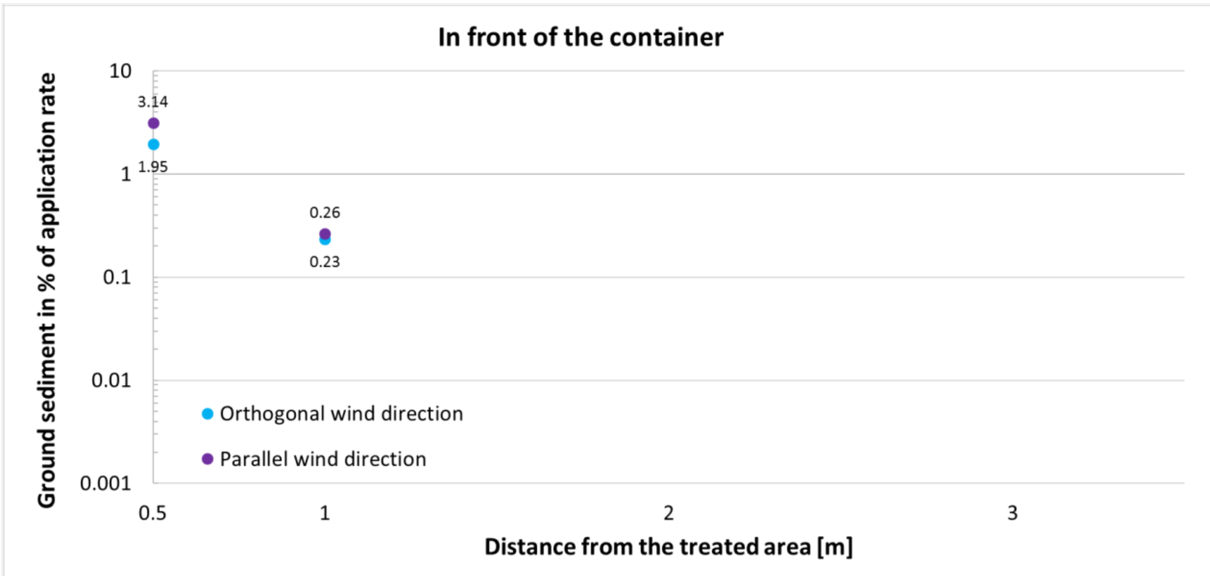
Figure 14: Surface distribution of the ground sediment at the knapsack sprayer application based on maximum values at orthogonal wind direction (left) and parallel wind direction (right).



Measured drift values

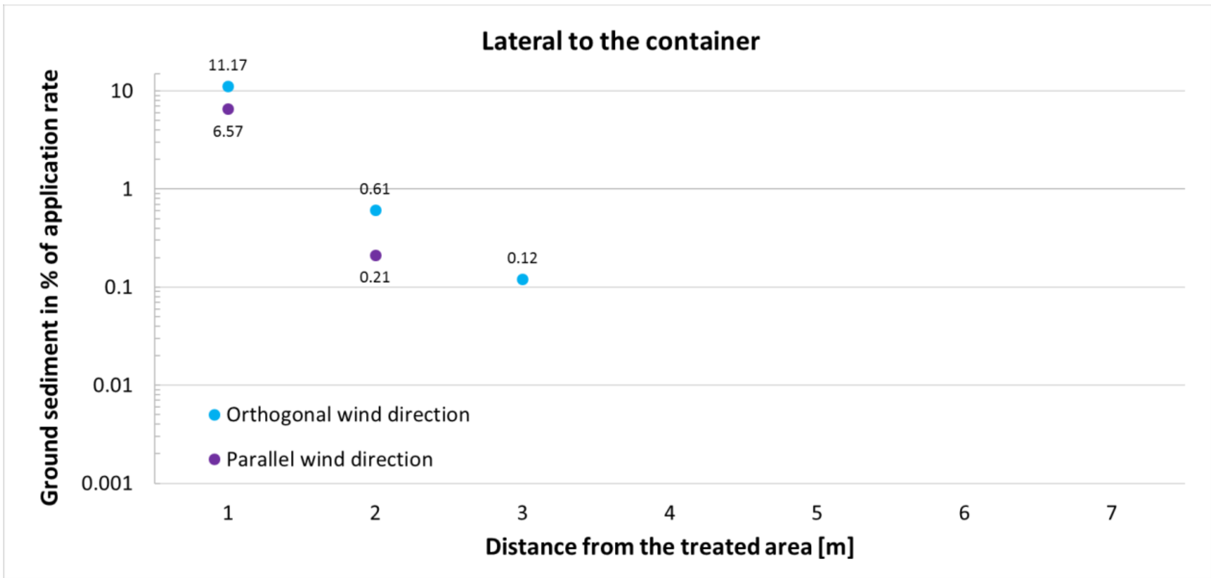
The measured drift values in percent of the application rate in Figure 15 and Figure 16 are conform to the surface distribution in Figure 14. The drift value of both wind directions decreased with increasing distance from the treated area but in general, the measured drift values are very low. Over the 15 petri dishes in front of the container (Figure 15) at a distance of 0.5 m, a maximum drift value of 2.46% and 1.95% of the application rate depend on the wind direction was measured. At the 1 m distance, the measured maximum drift values were very low with 0.26% and 0.23%. At the 2 m and 3 m distance, no direct drift was observed, because the measured drift values were under the limit of detection.

Figure 15: Measured drift values in percent of the application rate at the knapsack sprayer application depending on the distance to the treated area in front of the container based on maximum values.



The measured drift values over the 3 petri dishes lateral to the container at different distances from the treated area are shown in Figure 16. At orthogonal wind direction, the maximum drift value was 11.17% at the 1 m distance and 0.61% and 0.12% at the 2 and 3 m distance. At 5 m and 7 m, no direct drift was observed, because the measured drift values were below the limit of detection. At parallel wind direction, the measured maximum drift value of 6.57% was observed at the 1 m distance and 0.21% at 2 m distance. In addition, no direct drift was monitored at the 3 m distance and further.

Figure 16: Measured drift values in percent of the application rate at the knapsack sprayer application depending on the distance to the treated area lateral to the container based on maximum values.



4 Discussion and conclusion

4.1 Control of OPM on oak trees

A compilation of all measured drift values for all application techniques and all trial areas for the control of OPM on oak trees is presented in Table 10. Thereafter, the drift values of the cannon sprayer application at the three trial areas, "solitary tree", "avenue" and "forest edge" are discussed. Afterwards the drift values of the application techniques cannon sprayer and UVA at the trial area "solitary tree" and the drift values of the application techniques cannon sprayer and helicopter at the trial area "avenue" are compared. As a result, basic drift values will be suggested and possibilities to reduce drift will be discussed.

Table 10: Compilation of the measured drift values depending on the distance to the treated area of the cannon sprayer, helicopter and UVA application to control OPM at an avenue, solitary tree and forest edge.

Distance from the treated area [m]	90th percentile				maximum values	
	Cannon Sprayer - Avenue -	Helicopter Airmix 110-05 - Avenue -	Helicopter ID-120-05 POM - Avenue -	Cannon Sprayer - Forest edge -	Cannon Sprayer - Solitary tree -	UAV - Solitary tree -
5	14.40	16.74	10.20	11.02	4.59	93.24
10	12.12	12.60	4.72	23.41	3.55	45.54
20	9.56	9.32	2.73	18.66	1.89	13.81
30	5.39	5.31	2.24	18.74	1.18	5.36
50	3.28	1.25	1.11	8.07	0.35	0.85
75	1.22	0.38	0.30	3.05	0.11	0.14
85	-	0.31	0.15	-	0.08	-
100	0.49	-	-	1.35	-	0.04

4.1.1 Comparison of the application technique and trial area

Comparison of cannon sprayer application at three different trial areas

The presented trials show that the cannon sprayer produced the highest drift values at the forest edge, little lower drift values at an avenue and essentially lower drift values at a solitary tree (Figure 9). The difference of the drift values between the trial areas can be explained by the different application methods. At the solitary tree, the application was conducted at the windward side under the tree and the cannon sprayer applied the liquid directly into the solitary crown. At the avenue, the cannon sprayer also applied the liquid directly into the crown from the windward side, but the distance to the trees and gaps between the trees may have influenced the drift negatively and resulted in a higher drift than at the solitary tree (Figure 9). At the forest edge, the cannon sprayed the liquid also directly into the crown but from the downwind side. It could be observed, that a part of the spray cloud did not penetrate the crown, but was sprayed beside the crown and drifted away. The measurement showed, that in the near distance of 5 m the drift values were lower than the drift values from 10 m to 50 m. The major part of the drift cloud was blown beyond the 5-meter distance (Figure 9). The quality and efficacy of this kind of application at the forest edge seems questionable. However, the evaluation of efficacy was not part of the study.

Comparison of the application techniques UAV and cannon sprayer

In comparison to the cannon sprayer application, a greater difference in the drift values was observed at the same solitary tree using the UAV. Table 10 shows that at 5 m and 10 m the drift values using the UAV were 10 times higher than using the cannon sprayer. From 20 m to 75 m, the drift values were more than twice as high. This was the result of the different spraying techniques. The cannon sprayer was mounted on a tractor, the driver could start and stop the cannon sprayer directly under the crown. The control of the flight of the UAV was more problematic. The pilot stood 50 m in front of the tree and an assistant stood with an angle of 45° between tree and pilot and gave signals when the UAV was next to the edge of the crown. Assuming the long distance and the perspective from the pilots' point of view, this was an inaccurate method of application because of the problems to apply only to the target area and because of the difficulties to maintain a constant height above the tree (Figure 17).

The first line of collectors was 5 m from the edge of the tree crown. As shown in Figure 11, the maximum value of drift was almost 100% at 5 m and it is possible that the UAV had sprayed the liquid directly into the collectors due to the inaccuracy of the method. To prevent these high drift values, a more accurate flight is necessary. The used UAV DJI Agras MG-1S has an integrated flight controller and radar sensor. This allows an automatic overflight of areas with different slopes. The UAV detects the terrain with the radar sensor and adapts the flight altitude. The flight plan and the flight settings are planned with a software and defined waypoints. When the UAV reaches the first waypoint, the application will start automatically. Becker & Steinmetz (2018) used this UAV for first trials. They tested the application technique and the biological effectiveness. In the trials within our study, it was not possible to use this technique, because the treated area was a 23 m tall tree and the radar sensor for measurement of the ground distance only works from 1.5 to 3.5 m. At this time, a UAV application with an automatically overflight is only possible in field crops or vineyards but not for solitary trees. Therefore, applications with UAV in high crops do not make sense at the time being.

Figure 17: Comparison of the application methods cannon sprayer (left) and UAV (right) regarding their application distance.

Comparison of the application techniques helicopter and cannon sprayer

The differences between cannon sprayer and helicopter can be explained by the difference in the air turbulence. As describe above, the used cannon sprayer was a ground-based device and applied the liquid directly upwards into the crown from the windward side towards the measuring area (Figure 2). Whereas the helicopter in the avenue sprayed downwards into the crown and only the wind carried the spray over the measuring area (Figure 5). However, due to air turbulence, there could be occasional air currents near the ends of the rotor blades. The NZAAA (New Zeeland Agricultural Aviation Association) reported a turbulent wake with a pronounced downwash in the central section of the boom at low forward speeds of less than 25 km h^{-1}. For speed of 50 km h^{-1} and more, the strength of these vortices and the downwash is reduced, resulting in a lesser overall turbulent airflow pattern (NZAAA 2013). In the present trials, the forward speed was 35 km h^{-1} and lay between these two scenarios. Therefore, the vortex lead to a pronounced downwash of the sprayed product. This and the different spray direction of these two devices could be the reason why the drift using the helicopter was lower than using the cannon sprayer.

Figure 18: Comparison of the application methods cannon sprayer (left) and helicopter (right) regarding their spray method.

Comparison of the application data

Independent of the measured drift values, the application data of all used techniques to control OPM showed great differences. Table 11 shows an overview of the data of the cannon sprayer, helicopter and UVA application at the avenue, solitary tree and forest edge. While the liquid rate using the helicopter at an avenue was 40 l ha^{-1}, the liquid rate using the cannon sprayer at an avenue was 18times higher (325 l ha^{-1}). In addition, the application time using the cannon sprayer was 75 times longer (10 min) than using the helicopter (8 s). This resulted in a 9-fold higher application rate per tree when using the cannon sprayer. Differences like this came into focus when using the cannon sprayer and the UAV at a solitary tree. The liquid rate using the cannon sprayer was four times higher (895 l ha^{-1}) then using the UAV (193 l ha^{-1}). In addition, the application time was twice as long. In summary, the cannon sprayer application showed the highest liquid rate, application time and application rate per tree in both trial areas, “avenue“ and “solitary tree“, compared to the helicopter and the UAV application. It should be noted again, that efficacy trials were not the aim of this whole trial. Whether a helicopter application with an application rate of 1.5 l per tree has the same efficacy than a cannon sprayer application (10 l per tree) should be evaluated in a separate study.

Table 11: Overview of the application data of the cannon sprayer, helicopter and UVA application to control OPM at the avenue, solitary tree and forest edge (approx values).

Experimental parameters	Cannon Sprayer - Avenue	Helicopter - Avenue	Cannon Sprayer - Solitary tree	UAV - Solitary tree	Cannon Sprayer - Forest edge
Liquid rate (l ha^{-1})	317	40	890	193	241.6
Working speed (km h^{-1})	1.5	ca. 35	1.5		1.5
Application time (min)	10:00	0:08	5:20	2:40	5:00
Treated area (m^2)	2875	2875	517	517	1800
Application rate per tree (l)	10	1.5	46	10	10
Valid measurements	9	15	8	6	7

A further observation using the cannon sprayer was the partly defoliation of the oak trees in all trial areas (Figure 19). This effect was not observed when using the helicopter or the UVA. The cannon sprayer generated a very high air velocity so that leafs and branches were torn from the trees during the application. Caterpillars of OPM develop poisonous hairs in the third larval stage. If a cannon sprayer is used and old nests containing these hairs are present, it is possible that the high air velocity of the cannon sprayer distributes the hairs.

Figure 19: A partly defoliation of oak trees after the cannon sprayer application.

4.1.2 Basic drift values for the authorisation procedure

An overview over basic drift values using the application techniques helicopter and cannon sprayer in different trial areas are shown in Table 12. As a comparison, the basic drift values for the application of plant protection products in hops are also included in the table. Hops was chosen due to the plant height. Hops could reach a height of 7.5 m (Biendl et al. 2012) and is a better comparison with oak trees than using apple trees as a comparison object. However, the basic drift values of hops were created using air assisted sprayer. Table 12 shows at the near distance, only the lowest calculated basic drift values in this study (helicopter with ID-120-05 POM nozzle at an avenue) lie at the level of plant protection products application in hops. Even higher basic drift values are detected using cannon sprayers. Not only the basic drift values for the different devices are vary widely, but also the application area has a strong influence. This makes it difficult to transfer basic drift values of plant protection products to biocidal products. Therefore, it is necessary to measure new drift values for biocidal application areas and biocidal application devices.

Table 12: Overview of basic drift values derived from the measured drift values in percent of the application rate dependent to the distance from the treated area (green) comparison to the basic drift value of hop growing (grey) based on 90th percentile.

Distance from the treated area [m]	Helicopter Airmix 110-05 at avenue $y = 22.603e^{-0.052x}$	Helicopter ID-120-05 POM at avenue $y = 9.367e^{-0.047x}$	Cannon sprayer at forest edge $y = 55.06e^{-0.038x}$	Cannon sprayer at avenue $y = 17.85e^{-0.036x}$	** Cannon sprayer at solitary tree $y = 5.533e^{-0.051x}$	Hop growing (JKI 2016)
5	17.34	7.41	* 23.41	14.91	4.29	11.57
10	13.30	5.85	* 23.41	12.45	3.32	5.77
20	7.83	3.66	* 23.41	8.69	2.00	1.79
30	4.61	2.29	17.61	6.06	1.20	0.56
50	1.60	0.89	8.24	2.95	0.43	0.13
75	0.42	0.28	3.19	1.20	0.12	
85	0.25	0.17			0.07	
100			1.23	0.49		

* Maximum value in the distance range 5 to 20 m of the 90th percentile 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.
** Basic drift values were based on maximum values.

4.1.3 Possible techniques to reduce drift in spray application

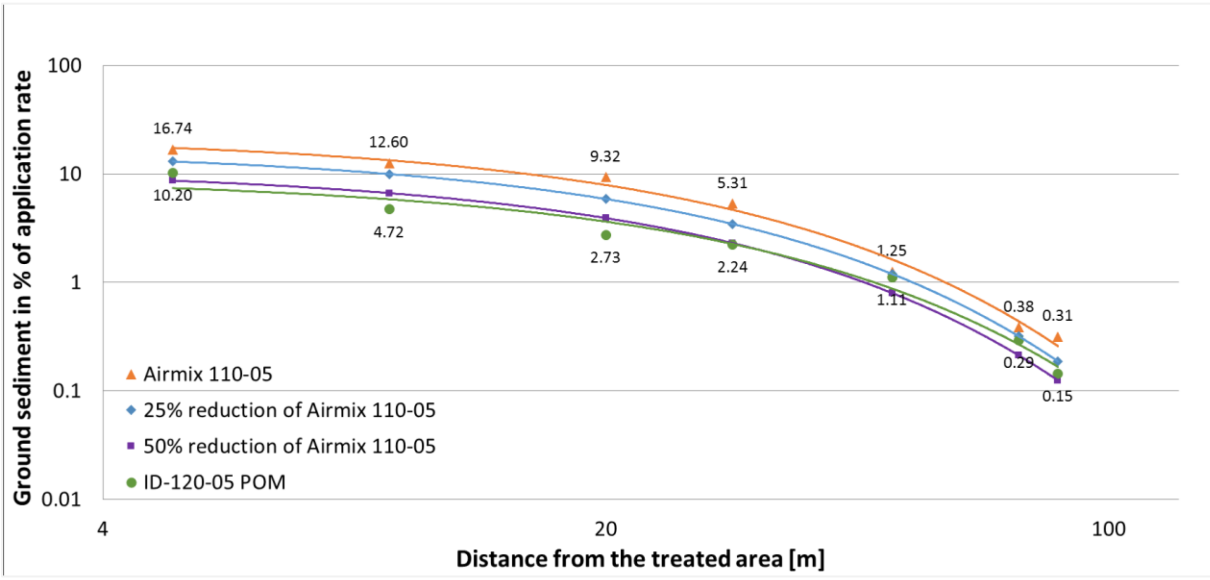
State of the vegetation in the field

Drift is influenced by the vegetation state in the field, like foliage and gaps between trees (Franke et al. 2010). As seen in the present trials, the drift values using the cannon sprayer were higher at the trial area “avenue“ than the trial area “solitary tree“. A reason for this could be the distance and gaps between the trees in the avenue. While the cannon sprayer applied the liquid directly into the crown of the solitary tree and the tractor driver could stop the sprayer at the end of the crown, the cannon sprayed the liquid onto the avenue along the driveway line regardless of potential gaps between the trees. To reduce the risk of drift between trees through gaps, a gap detection system would be necessary which detects the gap and thus shut off the spray system when passing it. Using a gap detection system for trees is difficult and so it currently only in use in apple trees and vineyard (Walklate et al. 2002; Escolà et al. 2007; Gil et al. 2007; Brown et al. 2008; Hocevar et al. 2010; Llorens et al. 2010; Overbeck et al. 2019). However, a transfer of a gap detection system to a cannon sprayer seems to be possible. Using a cannon sprayer at an oak avenue, the sprayer sprays the liquid upward into the crown and the sensors have to detect only the gap between trees in total.

Nozzle types

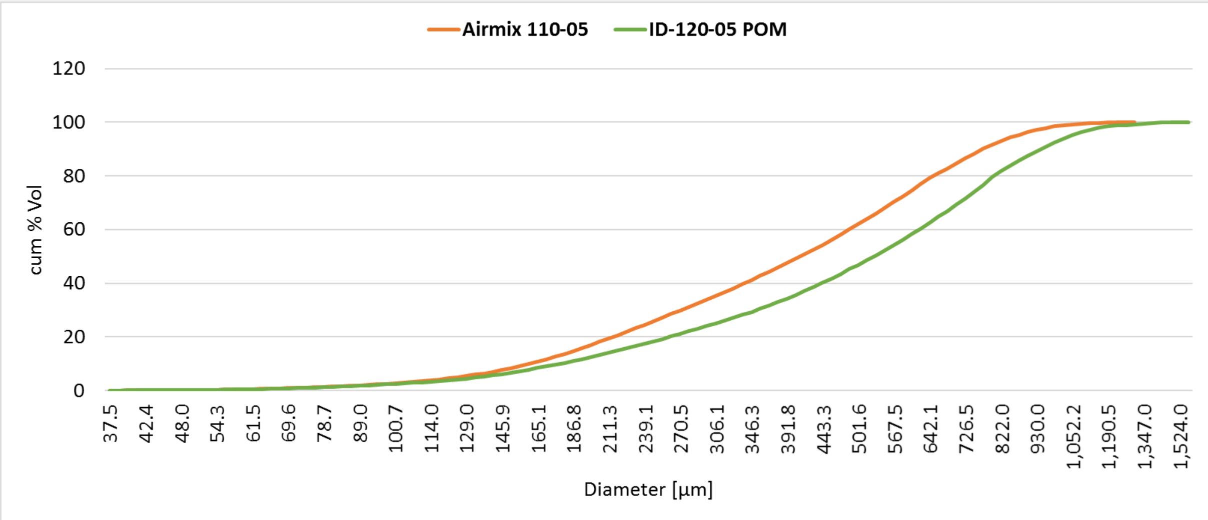
Different nozzle types are also possible techniques influencing drift (Franke et al. 2010; Hilz & Vermeer 2013); this was tested in equipping the helicopter with two different nozzles in the present trials. Figure 20 shows the known figure of the measured drift values in percent of the application rate at the helicopter application with two different nozzles and in contrast to the 25% and 50% reduction curve of the Airmix 110-05 nozzle. The 25% reduction curve lies considerably above the drift values of the ID-120-05 POM nozzle but the 50% reduction curve and the drift values of the ID-120-05 POM nozzle are similar. That means, using the ID-120-05 POM nozzle, a reduction of the basic drift values of 50% will be achieved compared to the Airmix 110-05 nozzle.

Figure 20: Measured drift values in percent of the application rate at the helicopter application depending on the distance to the treated area based on 90th percentile and the 25% and 50% reduction curve of the Airmix 110-05 nozzle.



This difference in the drift values could be a result of the nozzle character. The Airmix 110-05 nozzle and ID-120-05 POM nozzle are flat spray nozzles and were classified in a very large droplet spectrum at a working pressure of 2 bar (BBA 2002; JKI 2014). However, the classification of the drift potential is different. According to drift tests in the wind tunnel, the Airmix 110-05 nozzle reaches a drift reduction class of 50% at a working pressure of 2 bar in field crops (JKI 2018). In contrast, the ID-120-05 POM nozzle reaches a drift reduction class of 90% at the same working pressure of 2 bar (JKI 2018) in field crops. The droplet size distribution of these two nozzles and the cumulative volume of the drops depending on the drop diameter is shown in Figure 21. The amount of smaller droplets for the Airmix 110-05 nozzle is higher than for the ID-120-05 POM nozzle. According to Franke et al. (2010), droplets smaller than 100 µm in the spray fan are most vulnerable for spray drift and this fraction can be used as a first estimation of drift sensitivity of a nozzle.

Figure 21: Drop size distribution of the Airmix 110-05 nozzle and ID-120-05 POM nozzle measured with the "Oxford Lasers Imaging Systems".



An overview of droplet size parameters is given in Table 13. The volume 10% diameter (D_{V10}), the volume median diameter (D_{V50}), volume 90% diameter (D_{V90}), and percentage volume composed of droplets finer than 100 µm in diameter (V_{100}) were measured with the Oxford Laser Imaging System. D_{V10}, D_{V50} and D_{V90} are considerably lower for the Airmix 110-05 nozzle than for the ID-120-05 POM nozzle. The higher V_{100} value obtained for the Airmix 110-05 nozzle represent a higher drift risk, than the ID-120-05 POM nozzle. 2.74% of the sprayed volume was composed of drops finer than 100 µm using the Airmix 110-05 nozzle and 2.45% of the sprayed volume was composed of drops finer the 100 µm using the ID-120-05 POM nozzle. This confirms the hypothesis that the Airmix 110-05 nozzle has a higher drift potential compared to the ID-120-05 POM nozzle.

Table 13: Drop size parameter of the Airmix 110-05 nozzle and ID-120-05 POM nozzle measured with the "Oxford Lasers Imaging Systems".

Parameter	Airmix 110-05	ID-120-05 POM
D_{V10}	165.1 µm	181.1 µm
D_{V50}	416.8 µm	533.5 µm
D_{V90}	772.7 µm	959.1 µm
V_{100}	2.74 % vol	2.45 % vol

4.2 Control of crawling insects on house walls

4.2.1 Comparison of the measured drift values to the default values

A knapsack sprayer was used to apply a 1 m high stripe of liquid to the container wall to measure the direct drift while controlling crawling insects on house walls. The measured drift values in percent of the application rate grouped by two wind directions based on maximum values in comparison to the default values of the OECD are shown in Table 14. The OECD suggested a default drift value of 10% at a distance of 0.5 m from the treated area (OECD 2008). That is a 4 to 5 times higher value as observed in front of the container independent of the wind direction. At the 1 m distance, the measured drift values were 4 times lower at orthogonal wind direction to the treated area and half as high at parallel wind direction. However, lateral to the container, the measured drift values were 26 times (orthogonal wind direction) and 15 times (parallel wind direction) higher than the OECD values at the 1 m distance. It is noticeable, that the default values of the OECD considered an application stripe around the whole house independent from the wind direction.

Table 14: Measured drift values in percent of the application rate using a knapsack sprayer at two wind directions based on maximum values in comparison to the default values of the OECD.

Distance from the treated area [m]	In front of the container		Lateral to the container		OECD
	Orthogonal wind direction	Parallel wind direction	Orthogonal wind direction	Parallel wind direction	
0.5	1.95	2.46			10
1	0.23	0.26	11.17	6.57	0.42
2			0.61	0.21	
3			0.12		

4.2.2 Possible techniques to reduce drift in spray application

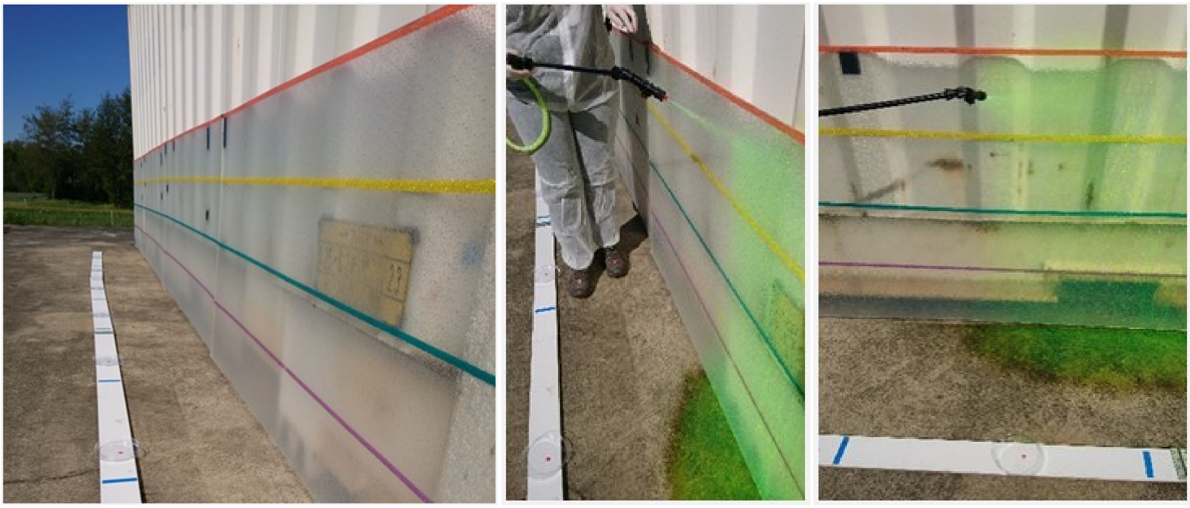
Wind direction

For the application of plant protection products, weather conditions such as temperature, wind speed, relative humidity, atmospheric stability, are the main factors that impact drift (Franke et al. 2010). The same is true for the outside application of biocidal products. However, the wind direction is not specified for plant protection products. These trials show clearly, that the wind direction affected the drift of biocidal products noticeably. The measured drift values are lower in front of the treated area when the wind direction had an orthogonal orientation to the application side of the container. At the same time, the drift values were higher lateral to the container, when the wind direction was orthogonal to the application side. Therefore, the wind direction should be considered in further discussions on how to reduce drift during the application of biocidal products.

Application height

The application height is an application factor, which impacts drift, but the definition of application height is different between the applications. In the plant protection sector, application height means the distance between nozzle and canopy. At the control of crawling insects on house walls, the application height means the height of the treated stripe. The distance between the nozzle and the wall is the same (Figure 22). These trials were conducted at an application height of 1 m. In further trials, applications heights of 0.25, 0.5 and 0.75 m will be used, assuming that a lower application height produces a lower drift. However, other application heights would have to be tested regarding efficacy in other studies.

Figure 22: Overview of the possible application heights of 0.25, 0.5, 0.75 and 1 m and the actual application height of 1 m for the drift value measurements at this trial.



5 Conclusion

There are some similarities between the application of biocidal products and plant protection products. In some cases, the same devices and the same nozzle types are used and the drift during the application is influenced by the same factors. At the same time, the targeted areas are very different, for example in height (oaks) and in general settings (house walls). For this reason, the transfer of basic drift values generated for the application of plant protection products does not seem reasonable.

It is noticeable, that some of the devices are forbidden for the application of plant protection products due to their droplet size and their drift potential, but the devices are not forbidden to apply biocidal products. A good example is the cannon sprayer to control OPM.

The present trials show that the tracer was still found at the maximum distances of the trials (85 m and 100 m) with all methods to control OPM, cannon sprayer and helicopter, and both tested nozzles, Airmix 110 05 and ID-120-05 POM. This shows that it is likely that biocidal products drift into non-target areas during the control of OPM, leading to potential risks for non-target organisms. However, the results also show possibilities to reduce the drift by choosing the technology least prone to drift. Of the three tested alternatives, this would be the helicopter using ID-120-05 POM nozzles. In addition, during the helicopter application a lower liquid rate, a higher working speed, a lower application time and application rate per tree were evident.

In general, the results show the importance to evaluate the equipment that is used to apply biocidal products. Until now, an evaluation of equipment for the application of biocidal products has not been conducted. It would be important to develop a comparable regulatory framework as it is already in place for equipment used to apply plant protection products. Only if more knowledge regarding the drift potential of the equipment used is available, the risk of drift into non-target areas can be reduced as much as possible.

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