International Standard

ISO 23117-2

First edition
2025-02

Agricultural and forestry machinery — Unmanned aerial spraying systems —

Part 2: Test methods to assess the horizontal transverse spray distribution

Matériel agricole et forestier — Systèmes de pulvérisation aériens sans pilote —

Partie 2: Méthodes d'essai pour évaluer la distribution transversale horizontale de la pulvérisation

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Reference number
ISO 23117-2:2025(en)

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CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
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Contents

Page

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 23, *Tractors and machinery for agriculture and forestry*, Subcommittee SC 6, *Equipment for crop protection*.

A list of all parts in the ISO 23117 series can be found on the ISO website.

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Introduction

The efficacy of plant protection products (PPPs) and their safety to the crop and environment are heavily influenced by spraying efficiency. The dose of the active ingredient(s) that is retained on target surfaces needs to be measured in a manner that is both accurate and precise, together with any assessment of variability in spray deposition.

The location, number and sampling structures used to monitor spray deposition needs to be defined in a standard manner to enable results from different tests to be compared.

A test can be set up to quantify or describe the in-field situation or for machine comparison. A spray system can be compared with a reference system.

ISO 5682-2 and ISO 24253-1 specify the standard test methods to assess the transverse spray distribution on a horizontal plane surface for ground vehicle mounted horizontal boom sprayers, but do not cover aerial spraying systems, including unmanned agricultural aerial sprayers (UAASs). UAAS is the combination of an unmanned aerial spraying system (UASS) fitted to an unmanned aircraft system (UAS).

UAAS operations from the aviation perspective are standardized in ISO 21384-3.

This document provides standard test methods to assess spray distribution in the transverse direction in a horizontal plane representing a flat soil surface or for example, a paddy field surface where the crop is very dense and of uniform height, using UAAS.

The popularity of UASs or drones and the continued advances in flight control, flight duration and payload potential has increased the suitability of UAS for agricultural purposes. However, use of specific UAAS can impact on the surrounding environment through spray drift or incorrect application of PPPs. Unmanned aerial spraying performance is dependent on a number of factors including nozzle/atomizer parameters, UAS rotor downwash, flying speed and height, the crop being sprayed and weather conditions.

The spray distribution of UASS is known to be significantly affected by the downwash effect of UAS so the performance of the spray depends on performance of UAS. Nozzle/atomizer arrangement in UAAS and application methods of UAAS are different from that of the ground vehicle mounted horizontal boom sprayers for field crops (deposition of which in a horizontal plane is covered in ISO 24253-1).

This document does not deal with the deposition of spray outside the treatment zone, that is lost as airborne spray drift, nor in canopy spray deposition in field and bush and tree crops from UASS. Standards regarding these measures of UASS performance are expected to be developed in future. Refer to ISO 22522 for tree and bush crops, ISO 24253-2 for the determination of canopy spray deposition and ISO 22866 for spray drift.

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Agricultural and forestry machinery — Unmanned aerial spraying systems —

Part 2: Test methods to assess the horizontal transverse spray distribution

1 Scope

This document specifies field measurements of spray deposition to determine the quantity and distribution of spray in a plane surface area in the transverse direction to the flight direction, treated by specific Unmanned Agricultural Aerial Sprayer (UAAS) with downward directed application.

These field measurements can be used to determine the effective swath width of UAAS.

This document is not appropriate for evaluating spray deposition within a crop canopy (three-dimensional deposition). It is not appropriate for those spraying systems which rely on the presence of a crop canopy for efficient spray deposition (for example directed spraying, electrostatic charged spraying, very fine sprays).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5681, *Equipment for crop protection — Vocabulary*

ISO 5682-1:2017, *Equipment for crop protection — Spraying equipment — Part 1: Test methods for sprayer nozzles*

ISO 21384-4, *Unmanned aircraft systems — Part 4: Vocabulary*

ISO 23117-1:2023, *Agricultural and forestry machinery — Unmanned aerial spraying systems — Part 1: Environmental requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5681, ISO 21384-4 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
unmanned agricultural aerial sprayer
UAAS
assembly of an unmanned aircraft system (UAS) fitted with all of the spraying equipment necessary for testing an unmanned aerial spraying system (UASS) filled with the required volume of the test liquid and if used, any additional devices/sensors for collecting test data

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3.2
spray pattern
transverse distribution of spray deposits applied by the UAAS

3.3
tracer
traceable material representing a plant protection product (PPP) to assess test spray deposition

3.4
tracer dose rate
quantity of tracer applied per unit area

Note 1 to entry: Expressed in kg/10 000 m^2 (kg/ha) for solids and l/10 000 m^2 (l/ha) for spray liquids

3.5
test liquid
mixture of water, tracer and/or plant production products (PPP) and/or additives which is sprayed during the test

3.6
test spray deposition
amount of spray liquid that is deposited on the collector(s) in the test

3.7
collector
artificial target to collect the sprayed liquid

3.8
flight route
pre-determined path taken by the UAAS

3.9
unidirectional application
spraying successive adjacent swaths with the same heading using the same nozzles/atomizers

Note 1 to entry: See Figure 1.

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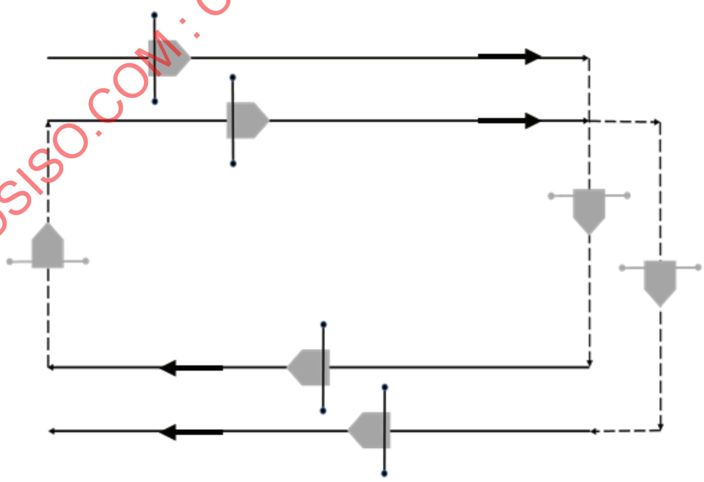

Figure 1 — Unidirectional application

3.10
progressive application with alternating heading and same nozzle/atomizer
spraying successive adjacent swaths with alternating heading using the same nozzles/atomizers

Note 1 to entry: See Figure 2.

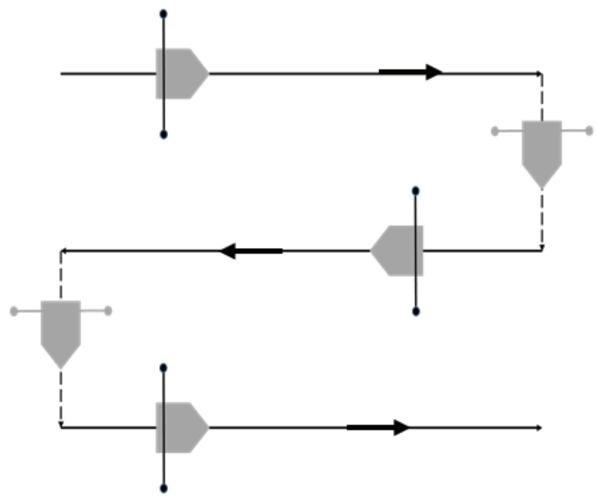

Figure 2 — Progressive application with alternating heading and same nozzles/atomizers

Note 2 to entry: The majority of small UAAS currently use progressive application (3.10, 3.11, and 3.12) for broadcast application.

3.11
progressive application with fixed heading and same nozzle/atomizer
spraying successive adjacent swaths with fixed heading using the same nozzles/atomizers

Note 1 to entry: See Figure 3.

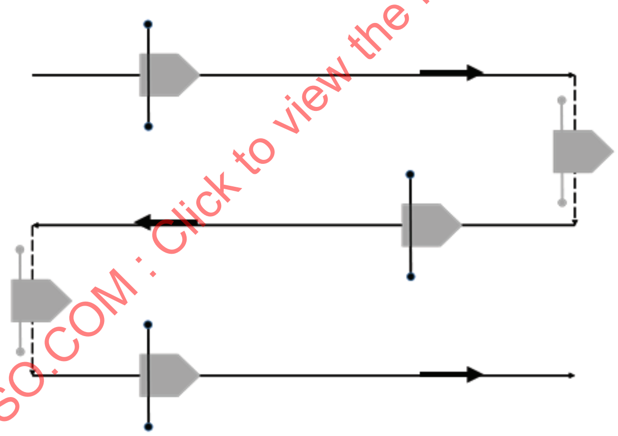

Figure 3 — Progressive application with fixed heading and same nozzles/atomizers

3.12
progressive application with fixed heading and alternating nozzles/atomizers
spraying successive adjacent swaths with fixed heading and spray system adjusting so that only rear nozzles/atomizers (relative to flight direction) are used for application in each pass

Note 1 to entry: See Figure 4.

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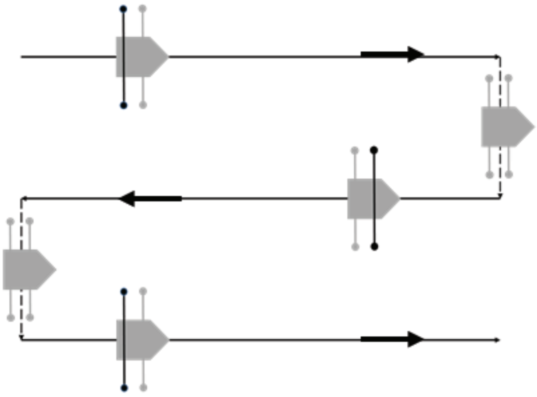

Figure 4 — Progressive application with fixed heading and alternating nozzles/atomizers

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3.13
centre of distribution
CoD
parameter defining the centre position of the spray swath from the deposition distribution

4 Test materials and requirements

4.1 Principle of test

Spray distribution depends on the operational parameters of the UAAS as well as the environmental and weather conditions, therefore the requirements provided in 4.2 to 4.6 shall be followed.

Spray distribution can be expressed as an absolute amount of spray liquid per unit area and/or in relative terms as a percentage of the intended spray volume or tracer dose rate.

4.2 Test site

The test site, which surrounds and includes the test area, shall have free areas to reduce the effect of surrounding obstacles affecting wind conditions in the test area. The test area shall be level ground with a gradient of 0 ± 2 %, with a bare soil surface or short mowed grass of maximum 8 cm height. The distance (*D*) in Figure 5 between the border of test area and surrounding vegetation or building may vary but shall be a minimum of 10 m or 10 times the height of surrounding vegetation or building height (*H*) whichever is greater.

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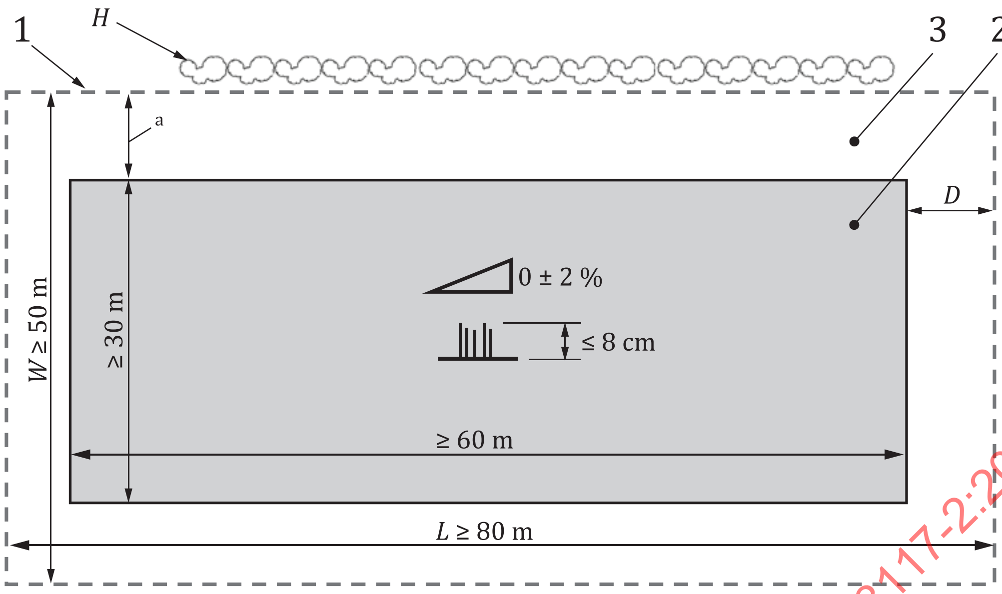

Key

1 border of test site
2 test area
3 free area
D distance between the border of test site and test area
H height of vegetation or building
L length of test site
W width of test site
[a] $D \geq 10$ m or $10 \times H$.

Figure 5 — Layout and size of test site

The length of test area in Figure 5 which is parallel to the flight route shall be greater or equal to 60 m. The width of test area shall be at least 30 m.

The flight route, the collector line and the take-off/landing position of the UASS shall be marked visibly in the test area. The minimum distance between the end of the collector line and the edge of the test area shall be 1,5 m. The test area shall have sufficient, equal, track length before and after the sampling area to ensure the intended liquid output from the UAAS is achieved over the sampling area. This length will depend on the size, and flight speed of the UAAS. To ensure consistency of liquid output, concentration within the sampling area and flight speed whilst spraying, the minimum flight distance whilst spraying shall include 20 m before and after the line of collectors (see Figure 6). Layout and size of the test site and the test area (as shown in Figure 5 and Figure 6) shall be fully reported with the test results. The size of test site is dependent on the size of the UAAS and application parameters and shall therefore be adjusted accordingly.

When spraying over a bare ground surface the ground surface conditions, such as ploughed surface or prepared seedbed, shall be recorded and reported.

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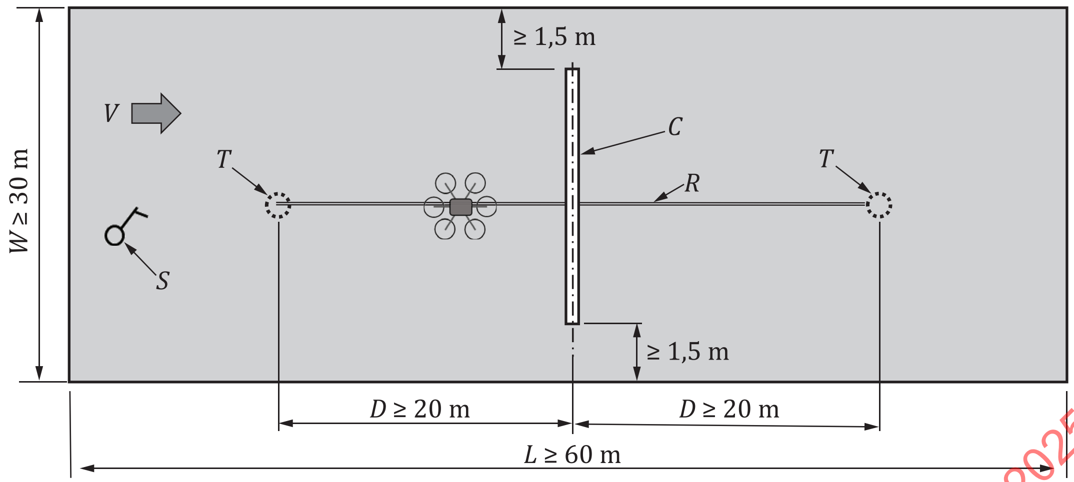

Key

C collector line

D distance for reaching stable spraying or returning

L length of test site

R flight route

S weather station

T take-off or landing point

V wind direction

W width of test site

Figure 6 — Configuration of test area

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4.3 Test equipment

All test equipment installed on the ground shall be calibrated according to the instrument manufacturer's recommendations and have the following maximum error as shown in Table 1.

Table 1 — Maximum error of test equipment installed on the ground

Test equipment	Maximum error
Anemometer	±0,1 m/s
Wind direction meter	±5°
Shielded thermometer for ambient temperature	±0,5 °C
Relative humidity sensor	±5 %

Image processing systems shall have resolution of 600 dpi or greater. Fluorometers and spectrophotometers shall have a maximum error of 1 % full scale.

4.4 Weather conditions

Weather conditions shall conform with the following parameters when measured at the minimum sample rate as shown in Table 2.

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Table 2 — Required weather conditions and minimum sampling rates

Parameter	Minimum sampling rate
Ambient dry temperature of 5 °C ~ 35 °C	1 s^{-1}
Relative humidity of 15 % ~ 90 %	1 s^{-1}
Mean wind speed of ≤ 3,0 m/s	100 s^{-1}
Wind direction within ±45° of the measured mean direction during the test	1 s^{-1}

Weather conditions (temperature, relative humidity, wind direction, and wind speed) shall be measured during the period 5 min before spraying, during spraying and 5 min after spraying. These measurements shall be taken at a location 15 m from the flight path upwind, once the flight route has been determined (see 5.2.1). Wind speed shall be measured at 1,5 m ± 0,1 m above the ground. Deposition data shall be excluded if the average wind speed is > 3,0 m/s or ±45 degrees of the measured mean direction during spraying test.

Temperature inversions (when an upper layer of air is warmer than the air below it) affect spray deposition measurements and increases the risk of spray drift, this shall be avoided by not conducting tests shortly (1 hour) before sunset or after sunrise if there are clear skies at sunset.

NOTE Temperature inversions can be detected by smoke or dust hanging in the air and/or only rising slowly.

4.5 Collectors

4.5.1 General

The sampling collectors shall have a flat surface and be horizontally positioned on the ground (see 5.2.4).

Sampling collectors shall be of the same type/material.

Care shall be taken to ensure that the sampling collectors do not saturate. This shall be checked before the test(s) by testing the collectors to be used with the expected recovered dose (or multiples of this).

Any collectors and/or different collector positions can be used as long as they shall provide equivalent results to the collectors and collector positions specified.

The results of the drop distribution measurements can be statistically evaluated in accordance with the analysis of variance (ANOVA), 10 %.

4.5.2 Collectors for quantitative (volumetric) measurement

Examples of quantitative collector materials which can be used are:

— filter paper;

— chromatography paper;

— filter material;

— Petri dishes;

— Kromekote papers.

Further information can be found in Annex C.

These collectors allow the volume of sprayed liquid recovered at each sampling location to be measured. This is done through using an appropriate tracer and dilution in the laboratory using the procedure described in Annex A, A.4.

The recovery of the sprayed tracer from the collectors shall be determined prior to the experiment. The collectors shall provide a minimum of 90 % recovery.

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Storage and handling of collectors should minimize changes in tracer recovery.

NOTE In the case of collectors used for quantitative assessment, the expected recovered volume (or multiples of this) can be applied by pipetting this evenly across the collector and visually checking that no saturation and/or run off occurs.

4.5.3 Collectors for qualitative (distributions/coverage) measurement

Examples of qualitative collector materials which can be used are:

— water sensitive papers;

— Kromekote papers.

These collectors allow information on drop distribution and spray coverage or area covered by droplets to be obtained. Quantification of drop numbers and coverage from these papers can be carried out with image analysis systems. Proper calibration of the image analysis systems is required (e.g. on pixel-size relation and background threshold/removal). Percentage of coverage or number of droplets per unit area on different collector locations can be presented (see Annex B).

Collectors used for qualitative analysis can be used only for visual assessment. Tracers and additives have an effect on the spread factor of the sprayed liquid on the collectors. The angle at which the droplets are incident upon the collector will also influences the stain size/shape. Very small droplets will be under-represented and high spray volumes can lead to saturation of the collectors.

Storage and handling of these collectors should minimize changes in stain distribution on the collectors after the treatment.

NOTE In the case of collectors used for qualitative assessment, the expected recovered volume can be applied using a spray which simulates the droplet spectrum and application rate which will be used during the test. This will demonstrate whether the number of droplet overlaps are above the level at which meaningful data can be extracted (although not necessarily a perfect representation of spraying in the test).

4.6 Test liquid

The spray liquid to be used for the purpose of the test shall have physical properties representative of liquids typically used in the application of PPPs. A representative test liquid can be achieved by addition of water soluble non-ionic surfactant at rate typically from a volume fraction of 0,005 % to 0,5 %, by following the surfactant manufacturer's recommendation using one of the following:

— clean tap water plus non-ionic surfactant if water-sensitive papers are used as the collectors;

— clean tap water with tracer plus non-ionic surfactant if glossy coated papers are used as the collectors;

— clean tap water plus non-ionic surfactant with tracers.

If oil or solvent based ULV (ultra low volume), or a ready-to-use product is the PPP of interest then either the actual PPP to be used or an appropriate blank representative of these formulations shall be used for the purposes of the test. Appropriate health and safety precautions shall be followed if PPPs are used.

The tracer shall be stable in field conditions with less than 5 % degradation for at least the total collection time of all collectors used in the test. The recovery of the tracer from the collector shall be at least 90 %, preferably 95 % (See ISO 24253-1:2015, 3.5).

The composition of the test liquid shall be documented in the test report.

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5 Test procedure

5.1 Overall test process

Test for assessing horizontal transverse spray distribution of an UAAS is conducted in five stages as in Table 3.

Table 3 — Five stages and actions needed in the test

Stage	Action needed
A	check weather conditions for 10 min to ensure the requirements of 4.4 are satisfied per 5.2.1
B-1	as specified in 5.2.1, determine the flight route based on the wind direction measured in stage A and mark visibly
B-2	load the test liquid on UAAS as specified in 5.2.2
B-3	test flow rate of nozzles/atomizers as specified in 5.2.3
B-4	position and secure the collectors as specified in 5.2.4
C-1	start measuring weather conditions as specified in 4.4
C-2	spray the test liquid while flying over the flight route during the stage C-1
C-3	check if weather conditions during the stage C-2 satisfy requirements of 4.4
D	if weather conditions are satisfied, collect and store the sprayed collectors as specified in 5.4.1 and 5.4.2
-	repeat actions from the stage B-3 to stage D until at least 3 sets of sprayed collectors under the same test condition (flying speed, nozzle height, etc.) are obtained
E-1	select the admissible collectors
E-2	evaluate spray deposition on collectors and calculate CV of a single pattern as specified in 5.5.1
E-3	determine the effective swath width as specified in 5.5.2

5.2 Preparation of the test

5.2.1 Determination of the flight route

Measure the weather data particularly wind speed and direction for at least 10 min prior to setting up the test to check if weather conditions in test site satisfy the requirements of 4.4.

The flight route of the UASS should be as close as parallel to the wind direction as possible (preferably within 15°), thereby minimizing the effects of crosswind on the spray pattern, with stable wind conditions required (see 4.4). Set the flight centreline and mark it visibly on the ground using rope or a series of short flag poles. Place the line(s) of collectors in the sampling test area at 90° to the direction of flight route while spraying.

If flying the UAAS in an automatic mode, a mission should be planned to fly the selected flight line at the defined operational parameters (height, forward speed) while achieving the desired flow rate/ application rate for the test along the specified flight line.

5.2.2 Loading the test liquid

The spray tank shall be filled to 50 % of its nominal volume as declared by the UASS manufacturer.

5.2.3 Flow rate test of nozzles/atomizers

Flow rates of nozzles/atomizers shall be tested in the stationary condition, i.e. with the spray system operating whilst the UAAS is not flying. Nozzle/atomizer flow rate shall be tested in accordance with ISO 5682-1:2017, 6.2. The test flow rate of each nozzle/atomizer shall be set within the operating range recommended by the UASS manufacturer, unless there is a specific alternative purpose. If this is the case both the flow rate used as well as the manufacturer's recommendation shall be reported.

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Individual nozzle/atomizer flow rates shall be measured with test liquid in the stationary condition while all nozzles/atomizers are spraying with a maximum error of ±5 % of flow rate recommended by manufacturer.

If oil or solvent based ULV, or a ready-to-use product is the PPP of interest then either the PPP or an appropriate blank representative of these formulations shall be used for the purposes of these flow rate tests. Appropriate health and safety precautions shall be followed if PPPs are used.

Calculate total flow rate of UASS and check if it satisfies the required spray volume per unit area assuming the flying speed and spray flight route spacing (or interval) to be used in the test.

Individual nozzle/atomizer flow rates shall conform with the requirement given in ISO 23117-1:2023, 5.4.5, Individual nozzle/atomizer flow rates and the total flow rate shall be reported in the test report.

5.2.4 Disposition of collectors

The sum of the total collector area can be adapted to attain the resolution of interest. The minimum requirements on the collector are:

— minimum size of a collector is 19 cm^2;

— maximum distance between adjacent collector’s, centre to centre, is 0,5 m.

The collector type, location and size shall be documented in the test report.

Position and secure the collectors along a line with maximum collector spacing of 0,5 m, at a height of 10 cm or less above the ground. The length of the collector line shall be longer than manufacturer’s declared spacing between flight routes, see Figure 7. The collectors shall be secured on bars or plates to ensure they do not change position or orientation due to the rotor downwash from the UAAS. Identification number of the collector starts from the left to the right of the spray-flying direction for the data analysis.

NOTE The collectors are fixed on bars or plates as the ground will not be a perfect plane.

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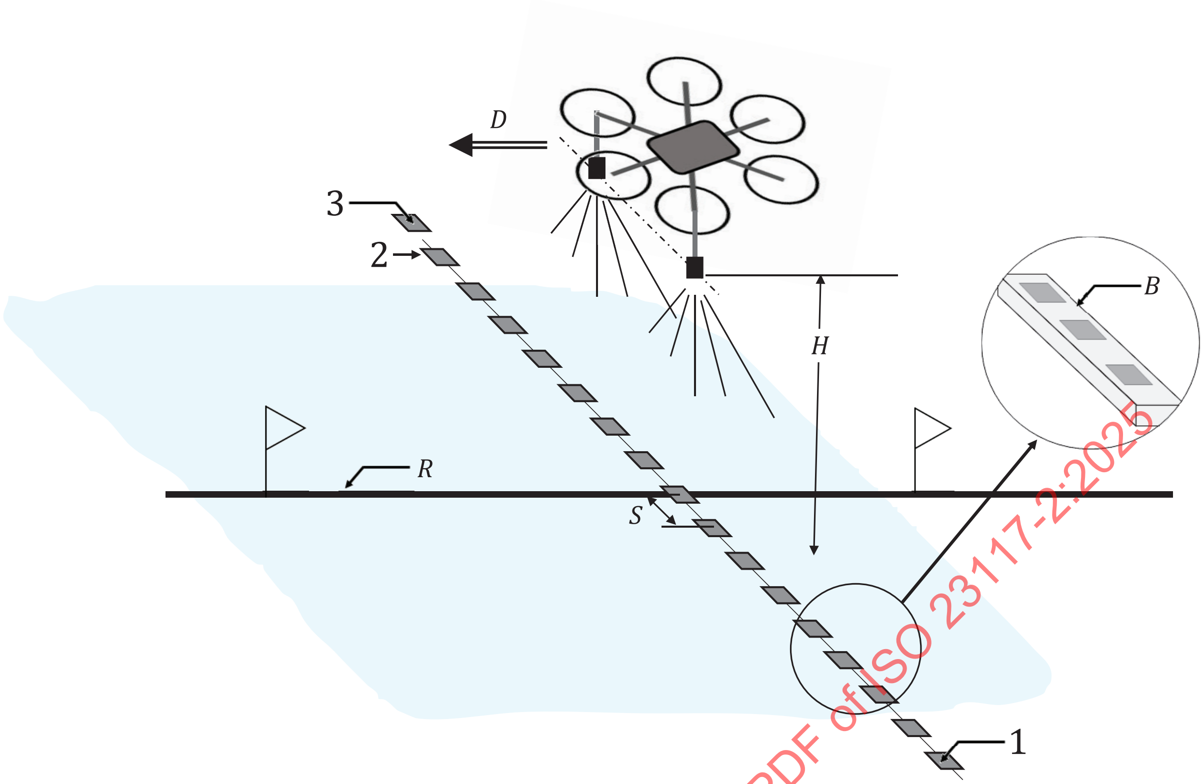

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Key

B bar or plate

D spray flying direction

H nozzle height

R flight route

S collector spacing

1 left end (1^{st}) collector

2 the (n-1)th collector

3 right end (n-th) collector

Figure 7 — Example of the collectors' disposition

5.3 Flying and spraying in the test

If flying the UAAS manually, it is important for the pilot to maintain the desired operational parameters (e.g. flight height, position on flight line and forward speed).

A UAAS spray deposition test shall be repeated at least three times to allow for the influence of weather conditions, particularly wind speed, wind direction and the complexity of rotor downwash/ground effects with associated variability in results, i.e. spray patterns, achieved. The more flight replicates that can be undertaken the more confidence there will be in determining spray patterns and the swath width achieved (since individual test flights can produce significantly different data).

Collectors need to be removed and stored (for separate analysis) following each test spraying flight/pass.

Nozzle/atomizer type, size, arrangement/configuration and height and the flight speed when spraying in the test shall be that recommended by the UASS manufacturer unless there is a specific alternative purpose (but the manufacturer's recommendation shall also then be documented in the test report).

It is imperative to ensure the UAAS is flown straight and level throughout the test and any deviation from the flight centreline shall be recorded in the test report.

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5.4 Data collection

5.4.1 Handling of collectors

IMPORTANT — When water sensitive paper (WSP) is used to get visual information on spray distribution, handling WSPs in a gloved hand to prevent colour change is necessary.

Procedures for handling spray collectors both prior to and post exposure to the test spray to minimize the risk of cross contamination shall be established.

The potential for cross contamination and tracer degradation shall be monitored during the test using clean collectors and those loaded with a measured volume of the spray liquid (see Annex A, A.4).

5.4.2 Collection and storage of collectors

After spraying, gather the collectors as soon as possible following the tracer requirements (within 30 min at most), code them with a reference and store them in a dark, dry and cool place depending on the properties of tracers. Collectors for image analysis should be dried and stored to prevent any corruption of the collector image.

Extract the tracer or active ingredient from the collectors and determine the test spray deposition (for example using a fluorimeter/spectrophotometer as described in Annex A) under laboratory conditions.

5.4.3 Determination of background emissions

Background emission from the collectors shall be determined using the provisions provided in Annex A. The average reading of the blank collectors shall not be higher than 0,1 % of the average reading of the sprayed collectors. Accuracy of the measuring device, artificial collector types, and background emission from artificial collectors shall be recorded and chosen to obtain a coefficient of variation of the background emission lower than 10 % (of at least 10 collectors; see Annex A).

5.4.4 Selection of admissible collectors

Measure the test spray deposition on the collectors in each collector line and calculate the mean of spray deposition for each line. Compare the deposition on each collector with the mean value of the collector line from which it came. If deposition on either of the collectors initially positioned at each end of the line is found to be more than 1 % of the mean value of deposition of that collector line, all test data from that test flight/pass shall be discarded. The test should be repeated with a wider array of collectors.

5.5 Data analysis

5.5.1 Statistical analysis

The results of the drop distribution measurements can be statistically evaluated in accordance with the analysis of variance (ANOVA),10 %.

5.5.2 Assumed uniformity of distribution

The coefficient of variation (CV) can be used to determine and express the uniformity of distribution of the spray pattern from a single test spray pass over a horizontal plane surface such as a flat field. The data for each individual replicate spray pattern shall first be graphed as a single pattern in relation to the flight centreline as shown in Figure 8 before any totalling or averaging of the results as a check for anomalies/outliers contained in the data sets (which can be due to malfunctioning of the spray equipment or incorrect installation and/or calibration), which shall be discarded if this is the case (simple averaging without this pre-analysis can mask significant variations in the spray pattern between replicates). Data from at least 3 usable replicates of the measured transversal spray deposition are required to calculate effective swath width.

NOTE 1 The concept of CoD has been developed as a method of determining whether the spray pattern is formed in the target area, but researches on CoD have not been accumulated enough to be used in UAAS performance evaluation. For more information, refer to the Annex E.

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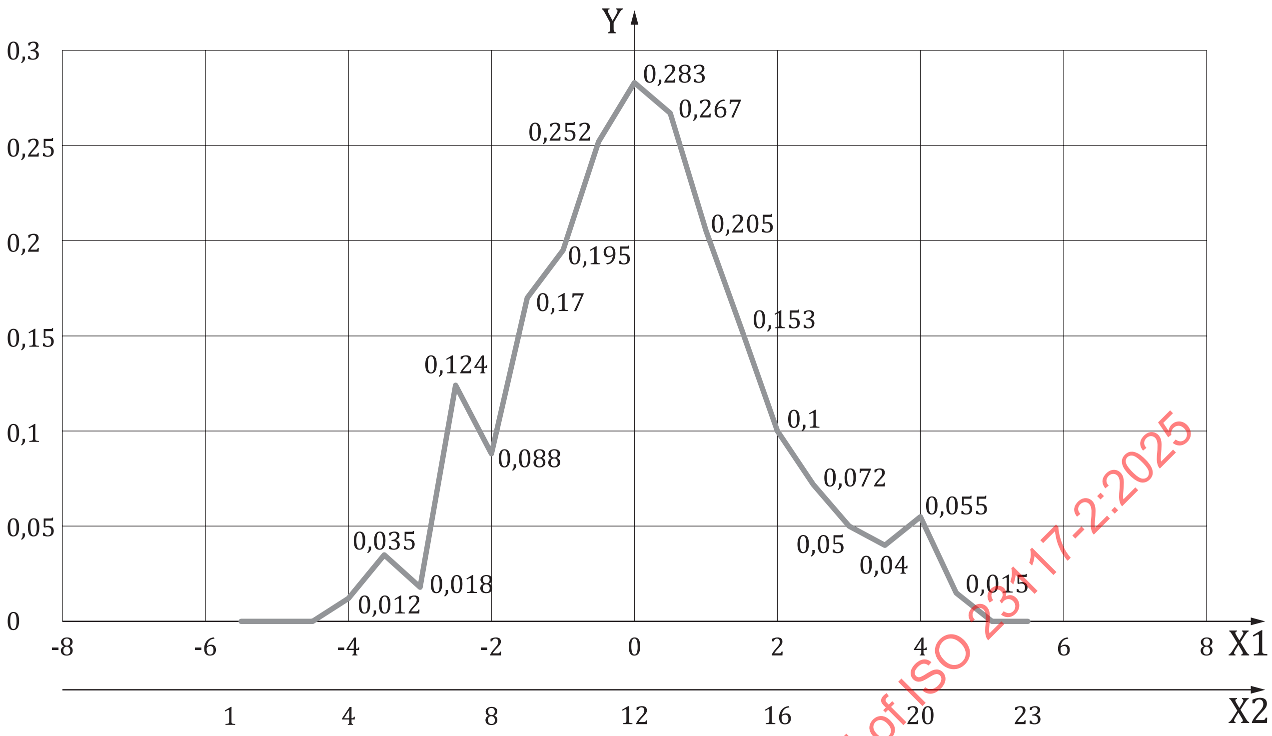

Key

X1 transverse location(m)

X2 collector number

Y spray deposition

NOTE Collectors were positioned from -5,5 m to 5,5 m.

Figure 8 — Example of spray deposition in the transverse direction

Figure 8 shows an example of a single spray pattern which was obtained from 23 collectors positioned from -5,5 m to 5,5 m in the transverse direction (x-direction), normal to the flight route.

These graphs are then overlapped as multiple adjacent swaths to obtain a composite graph showing simulated overlapping deposition patterns, with the flight centreline separation adjusted if necessary. Spray patterns are generally not symmetrical, so graphs should be prepared for both unidirectional and progressive applications with alternating heading.

In the case of unidirectional and progressive application with fixed heading, no reversing of adjacent swaths is required as the right side of the spray pattern will overlap onto the left side of the spray pattern of the previous swath. In the case of progressive application with alternating heading, it will be necessary to reverse the simulated adjacent swaths as the right of the spray pattern will overlap onto the right of the spray pattern of the previous swath.

NOTE 2 This assumes that progressive application with fixed heading will have the same theoretical deposition pattern on adjacent swaths which might not be the case.

If the UAAS operates in automatic mode in only one of these application types (unidirectional, progressive application with alternating heading and same nozzles/atomizers, progressive application with fixed heading and same nozzles/atomizers, or progressive application with fixed heading and alternating nozzles/atomizers) then it may be preferable to only carry out measurements for this application type.

Only the central portion of the overlapped deposition data shall be used to calculate the CV and this portion shall be recorded in the test report diagram relating to the layout of collectors. If the effective swath width is equal to or greater than 50 % of the total spray pattern width, this shall include data from one swath centreline to the next for unidirectional spraying or the data from the centreline of the first swath to the centreline of the third adjacent swath for progressive spraying. If the effective swath width is less than

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50 % of the total spray pattern width, additional overlaps shall be added until the region for calculation is unaffected by the addition of deposition data from additional overlapping swaths.

The CV needs to be calculated for both unidirectional and progressive spray passes for effective swath centreline spacing ranging from one sampling interval width to the total width of the single swath pattern (swath increments from this calculation shall not be greater than the sampling interval across the effective swath).

The average test spray deposition ($\bar{d}$) is given by Formula (1)

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n} \tag{1}$$

The definition of CV is given by Formula (2):

$$CV = \frac{d_{STD}}{\bar{d}} \times 100\,\% \tag{2}$$

where $d_{STD} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(d_i - \bar{d}\right)^2}$, the standard deviation of the deposition.

NOTE 3 The maximum allowed CV value in JAAA (Japan) and KS (Korea) is 30 % at present.

The results of all deposition measurements shall be statistically evaluated in accordance with the analysis of variance (ANOVA), 10 %.

5.5.3 Determination of the effective swath width

For the evaluation of the effective swath width, CV values for numerical superposition of the measured spray distributions at various distance (multiple of the collector spacing or 0,5 m) between fictive flight lines shall be calculated. It is recommended that the initial distance between flight lines is recommended between three times of the characteristic dimension of UAS and one half of the range of a single spray pattern as multiples of 0,5 m.

Using the measured single spray pattern, determine patterns of adjacent flight in both left and right side of the single flight (See Figure D.1 in Annex D). The spray pattern in unidirectional application would be the same as the single spray pattern. The distribution of adjacent reverse flying in the progressive application with fixed heading and same nozzles/atomizers is not the reverse of the first distribution because an UAS is changing its direction without rotation. However, the distribution of adjacent flying in the progressive application with alternating heading and same nozzles/atomizers would be the reverse of the single spray pattern.

Evaluate overlapped deposition value by adding deposition values of offset spray pattern at each collector position within the range of the single spray pattern and calculate the CV. The effective swath width is determined by deciding allowable or admissible uniformity of horizontal transverse spray distribution. The effective swath width is the distance between adjacent flight lines resulting in the required uniformity of spray deposit (i.e. coefficient of variation). Figure D.1 c) in Annex D shows overlapped spray patterns with four different distances between flight route. In this example, the effective swath width is determined as 5 m when based on a target CV value of 30 %.

The effective swath width shall be determined three times using 3 different sets of data for single spray pattern. The three effective swath widths and average of them shall be reported in the test report with the target CV value.

NOTE Effective swath width is valid only for the UASS at the test condition.

If a spray pattern satisfying the desired CV criterion has been achieved flying parallel to the mean wind direction it is possible to study cross wind effects on this spray pattern, if desired, by changing the test flight route relative to the mean wind direction.

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6 Test report

6.1 Data related to the UASS and UAS

6.1.1 General structure

The test report shall contain the;

— manufacturer of UASS;

— UAS type and model;

— UAS year of manufacture (if known);

— mass of UAS (kg);

— mass of UASS(kg);

— maximum spray payload (kg);

— mass of UAAS, with maximum payload (kg);

— mass of UAAS, with spray tank filled with 50 % of the nominal tank volume (kg);

— nominal battery voltage of system (for battery powered systems).

6.1.2 Rotor system

— diagram of rotor placement and dimensions;

— number of rotor axis;

— diameter of rotor (mm);

— nominal rotational speed of rotor (rpm) or motor kV value (RPM/Volt);

— characteristic dimension (mm).

6.1.3 Flight/Spraying control

— automatic spray control mode or manual spray control mode

6.1.4 Sensors (models and accuracy)

— ground position sensor;

— height sensor;

— other sensors if used.

6.1.5 Nozzles/Atomizers

— configuration of the spray boom if present;

— type and size of nozzles/atomizers (and nozzle/atomizer manufacturer);

— nozzle/atomizer distance (mm) from GNSS sensor (height sensor, if used);

— spray quality/VMD;

— pump type, specification;

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— pump working pressure of hydraulic energy nozzles/working rpm of rotary atomizers;

— flow rate (l/min) with specified value declared by the manufacturer and actual value measured in the test.

NOTE 1 Nozzle/atomizer height = flying height – nozzle/atomizer distance from GNSS sensor.

NOTE 2 Spray quality classification is defined in ISO 25358.

6.2 Data relating to the test conditions

6.2.1 Weather conditions

— ambient dry temperature (°C);

— relative humidity (%);

— mean wind speed (m/s);

— mean wind direction (degree).

6.2.2 UASS working conditions

— flying speed (km/h or m/s);

— flying height (m).

6.2.3 Data relating to the test site

— schematic diagram of the test site and area corresponding to Figure 5 and Figure 6;

— bare ground or vegetation (type and maximum height, cm);

— slope(gradient) of the test area (%).

6.3 Data relating to the test liquid

all test liquid ingredients shall be reported;

— tracers (ID e.g. colour index number, batch), additives, PPP used;

— tracer (or PPP) concentration (active ingredient, tracer, additive);

— tracer concentration of the spray liquid taken (preferably at the nozzle/atomizer outlet) immediately before and after spraying.

NOTE Specific rheological parameters, e.g. viscosity and surface tension, at 20 ± 2 °C and temperature during the test can also be of interest to record and report.

6.4 Data relating to the collectors

— diagram (with dimensions) showing placement of collectors relative to flight centreline and test area as shown Figure 6, indicating/marking which collectors were used in the calculation of the coefficient of variation (CV);

— type of collectors;

— size (mm) and shape of collectors;

— collector height from the ground (cm);

— collector fixing device.

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7 Expression of results

The spray distribution shall be evaluated for single spray pattern and (simulated) overlapped spray pattern.

For single spray pattern, the test spray deposition shall be expressed in amount of spray liquid or tracer per unit area (e.g. µl/cm^2, ng/cm^2), % of spray volume applied, % of coverage of a collector or number of droplets per unit area on different collector locations.

For overlapped spray pattern, the effective swath width shall be determined by assuming various CV levels (for example, 20 %, 30 %, 40 %), using the deposition data for single spray patterns and simulating overlaps as described in 5.5.3. The mean or median deposition and minimum and maximum deposition values and deviations are also relevant.

The test report shall provide the following information:

— variation in deposition, expressed as coefficient of variation (CV);

— mean or median deposition values (spray liquid or tracer per unit area (e.g. µl/ cm^2, ng/ cm^2), % of spray volume applied and/ or % of maximum spray volume recovered, % of coverage of a collector or number of droplets per unit area);

— deposition value at each collector location (spray liquid or tracer per unit area (e.g. µl/ cm^2, ng/ cm^2), % of spray volume applied and/ or % of maximum spray volume recovered, % of coverage of a collector or number of droplets per unit area);

— maximum deposition values (spray liquid or tracer per unit area (e.g. µl/ cm^2, ng/ cm^2), % of spray volume applied and/ or % of maximum spray volume recovered, % of coverage of a collector or number of droplets per unit area);

— minimum deposition values (spray liquid or tracer per unit area (e.g. µl/ cm^2, ng/ cm^2), % of spray volume applied and/ or % of maximum spray volume recovered, % of coverage of a collector or number of droplets per unit area);

— effective swath width for desired CV value (m, %).

Once an effective swath width/ distance between adjacent flight lines has been calculated as described in 5.5.2, then the application rate (A) can be calculated using Formula (3):

$$A = 600 \frac{Q}{V \times S} \tag{3}$$

where

A application rate (l/10 000 m^2);

Q flow rate (l/min);

V flight speed (km/h);

S effective swath (m).

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Annex A
(informative)

Fluorimetry/Spectrophotometry and deposition calculation

A.1 General

Fluorimetry is a well-known quantitative measurement technique for spray deposition and spray drift with accuracy up to 10 ppb. When fluorescent dye is used as a tracer, it is important to optimize the excitation and emission wavelength of the fluorimeter to the tracer to maximize discrimination of tracer and background fluorescence. Noise or background fluorescence can come from the collector, the dilution liquid (e.g. fluorescence of tap or demineralized water can change in time) and the pollution of the capillary (measuring) cell in the fluorimeter. When collectors are placed on ground surface care has to be taken about the background fluorescence from the contamination by dust from ground surface.

Spectrophotometry is a relatively cheap and easy quantitative measurement technique with reasonable accuracy of 1 ppm or lower. A spectrophotometer is commonly used for the measurement of transmittance or reflectance of solutions, transparent or opaque solids or gases. Each molecule will absorb light of specific wavelengths. The amount of light which passes through the material is indicative of the concentration of certain chemicals. A spectrophotometer is composed of light source, monochromator, detector, and sample chamber that is a cuvette made of glass or quartz. Tracers such as metal ions and food dyes which show strong solubility can be measured by the spectrometry using a calibration curve. Food dyes are stable and nontoxic. Synthetic food dyes are not present in nature, so background reading for these should be zero unless there is contamination.

A.2 Reading fluorimetry/spectrophotometry and calculation

Soak collectors with dilution liquid to get the tracer into solution. Minimize the volume of the dilution liquid to maximize fluorescent/water soluble tracer recovery, but it is dependent on the collection area and the spray content caught. The dilution volume and the amount of tracer on the collector also determine the recovery from the collector surface. Investigate in advance the optimal dilution volume and time necessary for the tracer to get in solution.

The reading of the fluorimeter/spectrophotometer is related to the amount of tracer in solution through a calibration curve. This curve, within limits of the scale is a straight line (e.g. 10< x <950 of 0 – 1 000), and determined through sampling known concentrations of the tracer.

Calculate from the reading of the fluorimeter/spectrophotometer, the calibration line, the collector surface area, the tracer concentration in the spray liquid, the background fluorescence (collector and dilution liquid), and the volume of dilution liquid, the amount of spray deposition per unit area can be calculated, e.g. in µl/cm^2, in accordance with Formula (A.1). From this spray deposition, the percentage of spray deposition on a collector can be calculated by relating the spray deposition to the amount applied in the field on the same unit of area, in accordance with Formula (A.2).

$$\beta_{dep} = \frac{(\rho_{smpl} - \rho_{blk}) \times F_{cal} \times V_{dil}}{\rho_{spray} \times A_{col}} \tag{A.1}$$

$$\beta_{dep\%} = \frac{\beta_{dep}}{(\beta_V / 100)} \times 100 \tag{A.2}$$

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where

β_{dep}	is the spray deposition, expressed in microliters per square centimetre (µl/cm^2);
$\beta_{dep\%}$	is the spray deposition percentage (%);
β_V	is the spray volume, expressed in liters per 10 000 m^2 (l/10 000 m^2);
ρ_{smpl}	is the fluorimeter/spectrophotometer reading of the sample;
ρ_{blk}	is the fluorimeter/spectrophotometer reading of the blank (collector + dilution water);
F_{cal}	is the relationship between fluorimeter/spectrophotometer reading and tracer concentration [(µg/l)/fluorimeter scale unit];
V_{dil}	is the volume or dilution liquid (e.g. tap or demineralized water) used to solute tracer from collector, expressed in litres (l);
ρ_{spray}	is the amount of tracer solute in the spray liquid, samples at the nozzle/atomizer, expressed in grams per litres (g/l);
A_{col}	is the (projected) area of the collector to catch spray, expressed in square centimetres (cm^2).

A.3 Background collectors

The determination of the background reading from collectors can be obtained by taking at least 10 collectors; soaking the collectors with the agreed dilution volume for the collector type; and determining the fluorescence/spectrophotometer value according to the protocol. The mean background value is determined from the individual fluorimeter/spectrophotometer readings.

It is advised to take up in the standard analysis procedure of the collectors from the test area to put a blank water sample and a blank collector for background determination at the beginning and at the end of the series of samples.

NOTE In case of spectrophotometry, background reading of collectors is not necessary.

A.4 Recovery of tracer from collectors

The determination of the recovery of the selected tracer from the chosen collectors can be obtained by comparison of fluorescence values obtained from the collectors for a specified quantity of tracer to the absolute measurement of fluorescence value for that same quantity of tracer.

Take at least 10 collectors and apply a specified amount of spray liquid with tracer evenly on the collector using a suitably sized pipette. Soak the collectors with the selected dilution volume and soaking time for the collector type and then determine the fluorescence/spectrophotometer value according to the protocol.

An absolute fluorescence/spectrophotometer value for this quantity of tracer should also be measured. This can be done by placing the same specified amount of tracer into the dilution volume with no collector, leaving an adequate amount of time for it to enter the solution. The fluorescence/spectrophotometer value of this can then be measured according to the protocol.

The ratio of the recovered tracer from the collectors to the absolute measurement will determine the recovery level of tracer from the collector.

The concentration of the applied tracer solution is preferably similar to the spray liquid concentration to be used in the field for the spray deposition experiment.

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Annex B
(informative)

Calculations and expression of the qualitative spray distribution results

B.1 Examples of collectors used for spray distribution measurements

— Water sensitive paper (WSP), commercially available in different sizes

— Kromekote cards (KC), commercially available one sided and two sided and in different sheets sizes

B.2 Measured spray distribution on collectors on the ground

Additional collectors such as those mentioned in B.1 can be placed at the collector positions prior to the test. After spraying of test liquid, spray deposition on the WSP or KC will be visible as a pattern of spots. The yellow coating of a WSP is turned blue where the droplets hit the paper. This pattern of spots can be analysed with image analysis systems and produce spray distribution parameters as percentage of area covered with spots and the number of spots per unit area.

Values of measured spray distribution shall be indicated as the percentage of area covered by spots (% coverage), and the spot number as number of spots per unit area (spots/cm^2).

Average spray coverage ($\bar{x}$) shall be given in percentage of the ground area.

Average spot number ($\bar{x}$) shall be given in spots/cm^2.

The CV of the measured spray distribution (% coverage or spot number) values or the maximum deviation (d_{max}) shall be reported.

B.3 Calculation

Average spray distribution (coverage of spot number) ($\bar{x}$):

$$\bar{x} = \frac{\sum_{i=1}^{n}(x_i)}{n} \quad \text{(B.1)}$$

where

n is the number of collectors;

$\bar{x}_i$ is the spray spots (coverage or spot number) collected on collector i.

Maximum deviation (d_{max}):

$$d_{max} = max\left(\frac{|x_i - \bar{x}|}{\bar{x}} \times 100\right) \quad \text{(B.2)}$$

Coefficient of variation (CV):

$$\text{CV} = \frac{d_s}{\bar{x}} \times 100 \quad \text{(B.3)}$$

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where

d_s is the standard deviation.

$$d_s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

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Annex C
(informative)

Examples of collectors for spray deposition measurement

C.1 Collectors for quantitative deposition measurement

The following are examples of collectors for spray deposition measurement:

— Filter paper (e.g. Schleicher & Schuel[1)]l no. , etc.);

— Chromatography paper (e.g. Whatman no. 2[1)], etc.);

— Filter material (e.g. Technofil[1)2)] TF-290 or TF-270, Camfil[2)] CF290, etc.);

— Kromekote cards (only coated both sides).

C.2 Collectors for qualitative deposition measurement

The following are examples of collectors for qualitative spray deposition measurement:

— Water sensitive papers (e.g. Syngenta[3)], AAMS, Spraying Systems[3)], etc.);

— Kromekote cards.

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