Recommendations for Conducting UAV Field Drift Trials

Proposed Field Study Protocol Guidance

Requirements & Specifications for Field Drift Trials
when using Unmanned Aerial Vehicles (UAVs)

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Developed by the Unmanned Aerial Pesticide Application System Task Force
(UAPASTF)

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1. Introduction

Changes have been incorporated into this document after commenting received from reviewers outside the Unmanned Aerial Pesticide Application System Task Force including experts in off-site movement research and pesticide regulatory agencies. Editorial corrections and substantial additions or corrections received from reviewers outside the UAPASTF were accepted throughout the document.

1.1 Purpose

This protocol "Requirements & Specifications for Field Drift Trials when using Unmanned Aerial Vehicles (UAVs)" describes a proposed framework of conditions under which spray drift research trials should be conducted.

The protocol describes the requirements, specifications, and parameters for conducting those measurements.

Note: Adjustments to local conditions, specific equipment, systems, and application characteristics (agriculture, vector control, vegetation management, etc.) are acceptable but need to be documented.

1.2 Background

Field trials and their data are important to generate reliable and comparable results to establish a uniform conclusion, statement, and meaning on direct drift values—on a global scale. Such data may be used for assessing off-target exposure (and subsequently risk) to non-target organisms or plants as well as for bystander or residential exposure. Therefore, it is of great importance to conduct trials following a standard trial design as closely as possible. This proposed protocol sets up the framework for these trials—from a scientific and statistical point of view—while keeping practical field handling in mind.

It is recognized that there is an International Standard (*i.e.*, ISO 22866; Ref. 6.1) that defines some of the methodology for field measurement of drift covering both ground deposition and airborne drift concentrations. Additional standards concern the conduct of drift studies in wind tunnel and field trials (*i.e.*, ASABE S561.1; Ref. 6.2). This protocol builds on the requirements in ISO 22866 but also considers requirements discussed and decided on during the Society of Environmental Toxicology and Chemistry Drift Risk Assessment Workshop (SETAC DRAW; Ref. 6.3) initiative around creating a revised protocol for drift trials when using standard spray tractor-based sprayers.

The described protocol is mainly intended for direct drift trials, yet it can be used as a guideline or reference for Occupational-Residential-Exposure (ORE, also including bystanders) drift trials as well, knowing that these trials must follow guidelines differing to what is described here. Yet, many aspects do apply to both and thus this protocol can also support conduct of ORE trials.

1.3 Rationale for airborne (3D) measurements

This protocol states that for assessing drift from UAVs, collectors may be placed vertically above the ground (airborne or 3D measurement) in addition to horizontal placement. This recommendation is based on also needing 3D measurements when assessing standard aerial application (*e.g.,* airplanes and crewed helicopters) regarding their drift potential. Even if UAVs are operated closer to the ground than crewed aerial applications, they might be evaluated by authorities as an aerial system. Thus, any UAV direct drift trial should ideally include 3D measurements and consideration of the unique characteristics and operational techniques of UAVs and the associated spray equipment. It should be ensured that vertical capture of residues do not interfere with horizontal residue capture.

1.4 Meteorological Data

On-site weather stations are required. During each trial, on-site meteorological data must be documented at the time of drift data collection. Most importantly, wind speed, wind direction, temperature, humidity, and atmospheric pressure should be taken at application height and these measurements, including application height, should be recorded in a manner that allows post-experiment analysis and characterization of temporal wind conditions. The frequency of measurements should also be documented in the context of average data being presented, along with maximum wind speeds and ranges of values. Conditions immediately prior to, and for at least 10 minutes after testing (*i.e.*, after sample collection is completed) should also be documented. For more detailed information on measurement and recording of meteorological data, see the Table of Requirements and Specifications below.

1.5 Good Laboratory Practice (GLP) Standards

Where applicable, Good Laboratory Practice Standards (GLP) will be used. However, based on the scope of the trial, it might not be necessary to conduct and label the trial as a GLP trial, but it should still closely follow these guidelines and align with the appropriate authorities, where possible. It must also be considered that even if a trial is set in accordance with GLP, it might not be labelled as such if the performing team or the lab isn't certified accordingly or have an established GLP program. The rationale and basis for deciding the GLP versus non-GLP conditions of the study should be documented and stated.

1.6 Machinery (Reference Sprayer)

A reference sprayer (*i.e.*, ground boom sprayer) should be used in each trial to compare against UAV. The reference sprayer settings (as described in Table Section 4, Machinery – Ground (tractor) Reference Sprayer (To be used as described)) should be maintained as close as possible in all trials such that it can be used to identify impact of environment (wind speed, temperature etc.) or operational parameters (flight height, speed, nozzle type, droplet spectrum etc.) when changing UAV setup.

1.7 Results and Archiving

Results are expressed in relation to the total amount applied to the target area. Drift curves can be generated using the differential distances covered during UAV application.

All results, meteorological data and on-site observations must be documented and archived. For more detailed information on recording and archiving, see the Table of Requirements and Specifications below.

1.8 Mandatory Requirements

Note: Requirements are specifically discussed here for the European Food Safety Authority (EFSA) and the United States Environmental Protection Agency (EPA), but local requirements should be considered relative to the appropriate authority.

Across the globe, certain guidelines can be used when conducting drift trials, such as the ISO standards mentioned above, or these Unmanned Aerial Pesticide Application System Task Force (UAPASTF) guidelines, yet some regions/countries may have more specific requirements for their local jurisdiction and/or purpose. This protocol thus adapts to these as far as possible, so that other regions/countries may also contribute to the global use of data generated. In general, following this protocol is intended to fulfill European Food Safety Authority (EFSA) and US Environmental Protection Agency (EPA) criteria, as well as the list of EFSA and EPA's mandatory scientific literature inclusion/exclusion reporting criteria as given in Appendix 5.3 (EFSA) and Ref. 6.4 (EPA). In principle, fulfillment is required for the data to be considered acceptable for inclusion in any EFSA data set or compilation, for example.

It is important to note that this protocol should be seen as a guideline and example on how to conduct a direct drift trial such that authorities can properly evaluate it. The situation in other regions might be different—yet it is in all UAV stakeholder's interests to align on a global protocol as much as possible even if the captured data are not used for registration purposes.

This protocol should be utilized as much as possible even if local requirements or resource constraints cause variations and deviations, which should all be documented along with the specific trial plan. Where possible, it is suggested that local requirements are included and documented as supplementary components building upon this protocol as a foundation (*e.g.*, additional sampler types/designs and placement etc.).

Note: To label a trial as a drift (or off-target movement) trial, it should follow this or similar protocols (e.g., ISO or SETAC DRAW standards). Measurements of just coverage adjacent to a sprayed area using artificial deposition samplers, such as water-sensitive papers (WSP), Kromekote paper, or colored dyes sampled as images on cards as an indicator or studies that do not include wind speed and/or direction do not represent a drift trial and should not be labeled as such.

1.9 Terminology

Spray drift
is the movement of atomized spray droplets or solid particles downwind, during or shortly after an application, which is deposited beyond the target area. Any amount lost from the target area due to evaporation, runoff, volatilization, or soil-bound erosion afterward cannot be considered as primary deposition drift.

A trial
is a number of direct drift collection events.

An event
is an application scenario with a set of collectors (*i.e.*, a replicate within a trial). A minimum of three replicates (events) are needed for each treatment (per ISO 22866, Ref. 6.1). The treatment list makes up the trial.

A drift line
is a single row of collectors stretching downwind from the edge of the sprayed area. Multiple drift lines (*i.e.*, minimum of three) are laid out for every single application to generate multiple deposition data points per distance used.

Note that these trial/line definitions are entirely consistent with those presented in a parallel drift protocol developed as a component of the SETAC DRAW workshop.

An Unmanned Aerial Vehicle (UAV)
commonly known as a drone or remotely piloted aircraft, is an aircraft without a human pilot on board. UAVs are a component of an Unmanned (a.k.a. Uncrewed) Aerial System (UAS); which include a UAV, a ground-based controller, and a system of communications between the two. The flight of UAVs may operate with various degrees of autonomy: either under remote control by a human operator or autonomously by onboard computers, which are configured and monitored by the operator(s).

A swath
is the treated area from one pass of the sprayer. The intended swath position may be impacted by variation in wind speed and direction.

A swath offset
Corrects the displacement of the intended swath position due to variation in wind speed and direction. Accounting for the swath displacement via swath offset is important to ensure the spray lands in the intended application area, and therefore any residues measured outside the treatment area are due to drift alone.

2. Table of Requirements & Specifications

The table is organized around different aspects of a drift trial. For each item, a type is stated by using the last four columns of the table. The types are:

- Minimum = the value must reach at least the given level
- Maximum = the value must not exceed the given level
- Mandatory = no variations are allowed
- Request = minor variations are allowed and/or it is known and acknowledged that the specific item only applies in a particular region/country and/or the item represents a “nice-to-have” aspect only.

Item		Requirement	Remarks	Type			
1.	**Repetitions and Replicates** Note: Types and number of samplers and distances differ significantly with Occupational-Residential-Exposure (ORE) trials. The general layout is visualized in Figures in Section 0.			Minimum	Maximum	Mandatory	Request
1.1	Number of replicates in any trial	≥3	Each spray event (*i.e.*, each replicate), with its specific settings, should be repeated at least 3 times if accompanied by a reference spray. If no reference spray is included, each spray event should be repeated many more times in order to account for variability in weather (note: some experts believe 35 replicates are necessary in cases where a reference spray is not included). For statistical purposes: target CI of 95%	X			
1.2	Repetitions of drift lines	≥3	At each measured distance, ≥3 collectors are laid out Separate drift lines by approximately 4 m	X			
1.3	Number of samplers	≥10 downwind ≥1 upwind ≥5 in swath	Example distances (may be adjusted to local conditions): Upwind: 10 m In swath: 5 equally spaced, covering the application area Downwind: 1, 2, 4, 8, 16, 32, 64, 128, 164, 200 m	X			
1.4	Closest point	1 m			X		
1.5	Furthest point	200 m	Refer to ASABE S561.1 (Ref. 6.2)	X			
1.6	Replicated trials over different growth stages	n.a.	If crop becomes a factor, 3 trials (each with a minimum of 3 replicates) across different crop growth stages may be considered if the applications are made at different crop stages If crop is assessed, a cross-referenced bare ground area needs to be included (see SETAC DRAW protocol as a reference)				X

Item		Requirement	Remarks	Type			
2.	**Test site = Treatment area & Measurement area** The area on which the trial is performed ("where the sprayer is") + the area on which the measurement is performed ("where the samplers are") See also figures of site layout, sampler placement, and other aspects in Section 0.			Minimum	Maximum	Mandatory	Request
2.1	Trial location	Level ground, Representative, Open with extensive upwind fetch that is clear of structures or objects The sites ought to be surveyed in 60° increments for future layouts to accommodate wind direction change Where possible, include at least 3 locations	Document the field elevation, latitude and longitude coordinates (*e.g.*, in Google Earth)			X	
2.2	Slope of the test site		Test area should be as level as possible Slope to be recorded (specify site upslope, downslope, % slope, slope limit recommended 3% max.)			X	
2.3	Surrounding area	No hills, trees or forests, hedges, or buildings on both sides (upwind and downwind) within 200 m of spray area	Generally, the surrounding should be as open as possible to have low wind disturbances Both sides (upwind and downwind) to be recorded			X	
2.4	Timing		Timing and rationale for its selection to be recorded (*e.g.,* morning due to low wind forecast and time of year) If crop becomes a factor, the timing should represent a typical timing of an application (*e.g.,* BBCH or V5) to be recorded			X	
2.5	Treatment Area	Area in which the sprayer is operating					

Item	Requirement	Remarks	Type: Minimum	Maximum	Mandatory	Request
2. Test site = Treatment area & Measurement area The area on which the trial is performed (“where the sprayer is”) + the area on which the measurement is performed (“where the samplers are”) See also figures of site layout, sampler placement, and other aspects in Section 0.						
2.5.1 Surface	Bare ground, grassland, or cropland	Farming practices recorded; cultivated following local conditions [Plant Protection Products (PPPs), fertilizer, *etc.*] Grassland must be mowed If crops are included in study, these should be clearly documented. If the trial uses a cropped surface, samplers in swath should be placed level with crop canopy to avoid losses due to interception			X	
2.5.2 Length	At least 2 x the drift sampling distance, to accommodate up to ±30 degree variation in wind direction from perpendicular and assure the farthest downwind collectors can actually be exposed to drift – *e.g.* if sampling drift to 200 m, the spray length must be ≥400 m	The length must cover the scenario that the potential drift will be driven by the wind with the maximum allowed deviation (30°).	X			
2.5.3 Width	40 m or at least 4 swaths With minimum 20 m sprayed + Minimum 20 m of equivalent cropped area upwind	Testing should include both single swath pass and 4 swath passes. 4 swath passes are conducted for all testing conditions, and the single swath pass is for representative conditions (*e.g.,* manufacture default setting or recommended setting for a given application rate). The purpose of the single swath pass is to understand spray pattern and swath offset which are important for data interpretation of 4	X			

Item		Requirement	Remarks	Type			
2. Test site = Treatment area & Measurement area The area on which the trial is performed ("where the sprayer is") + the area on which the measurement is performed ("where the samplers are") See also figures of site layout, sampler placement, and other aspects in Section 0.				Minimum	Maximum	Mandatory	Request
			swath passes.				
2.5.4	In-crop buffer		Could be a factor to investigate as a mitigation option If in-crop buffer becomes a factor, the minimum width is extended by width of the buffer				X
2.6	Measurement area						
2.6.1	Surface	Bare ground or grassland	Can be the same field (crop mulched) or the adjacent area (neighboring field) Grassland must be mowed			X	

Item		Requirement	Remarks	Type			
3. Machinery – Sprayer (depends on the test item) The sprayer should be a standard sprayer available on the market with a current state-of-the-art design. The application should be done in a typical local manner.				Minimum	Maximum	Mandatory	Request
The machinery and its setup can be a matter of the initial trial question and thus may vary across or within a trial program. If comparing crops and/or growth stages: For every trial and every test run, the same sprayer and setup must be used.						X	
3.1	Sprayer type	UAV	A detailed sprayer description (manu-facturer, type, size, make, age, etc.), as well as a description of the spray rate control system, *i.e.*, speed compensa-tion range of operation and whether the rate controller was used during the spray test must be documented and at-tached to the report			X	
3.2	Working width (Effective swath width)	May vary with factors such as boom length, and other oper-ating parame-ters (*e.g.*, flight height, speed, nozzle, etc.), but often around 3-5 m	When comparing different UAV types, a constant working width might be used if possible The UAV manufacturer may provide you with a theoretical swath width based on the spray system setup. It is important to verify this by measuring swath width as this is required to calibrate and establish the water volume (liter/ha, gallons/acre) delivered. Working width needs to be measured and recorded. See Appendix 5.5.1 for methodology to be used to estimate the effective swath width			X	

Item		Requirement	Remarks	Type			
3. Machinery – Sprayer (depends on the test item) The sprayer should be a standard sprayer available on the market with a current state-of-the-art design. The application should be done in a typical local manner.				Minimum	Maximum	Mandatory	Request
3.3	Working speed	May vary for different applications; 3-6 m/s as a comparative standard across studies, but constant working speed is required for each task. Same for other parameters.	Is given by choice of machinery + manufacturers' recommendation Flight speed should be measured by GPS signal or flight time during constant flight distance. When checking speed, fill the spray tank with water to simulate the anticipated payload of the application. Maintain a constant flight speed during application. Note exceptions: For example, some UAVs have a speed–flow (application rate) compensation system, if so equipped, describe how it was used			X	
3.4	Agitation	Not available on current UAV spray systems	Current models are not equipped with an agitation system. Ensure the solution is well dissolved and dispersed when loading into the tank and spray no more than 30 minutes after mixing. Report any sediments left in the tank or any other undesirable deposits etc.			X	
3.5	Water (carrier) volume	Target range of 18.7 – 40 L/ha	Target a minimum volume of 18.7 L/ha and a maximum of 40 L/ha. Note: other study designs may investigate water carrier volumes outside this range depending on the UAV platform and application purpose	X	X		
3.6	Calibration prior to trial	Calibration to be done at least the day before the trial or longer to allow time in case adjustments have to be made	Spray rate, pressure (a customized pressure gauge set-up can be used since UAVs don't come with pressure gauge), application speed, effective working width Each nozzle should have its flow rate measured at each application pressure Appendix 5.6 details the recommended approach to conducting the calibration			X	

Item		Requirement	Remarks	Type			
3.	**Machinery – Sprayer (depends on the test item)** The sprayer should be a standard sprayer available on the market with a current state-of-the-art design. The application should be done in a typical local manner.			Minimum	Maximum	Mandatory	Request
3.7	Sprayer position and timing	GPS position of sprayer at time of application (to be recorded)	Data should be useful to assess the UAV flight path, spray pump status (on/off) and speed afterward Most UAVs can record the spray operation. Use that information to transcribe the flight path. Data should be saved in native (proprietary) format if used by manufacturer and also converted to a generic file format, *e.g.*, kml or other 'as-applied' or aerial application format (Satloc, etc.)				X
3.8	Nozzles & Boom	Nozzle positioning (under rotor/on boom) and configuration or spacing should be recorded. Nozzle types and classification should be documented				X	
		General recommendations: Verify that the spacing is consistent to what is needed to provide the desired swath for the aircraft. Boom and nozzles should be positioned to avoid spray interference with the UAV framework or component (landing gear, radar sensors etc.). Otherwise, it will collect and fall off large droplets, wasting materials, and causing contamination and distortion of spray pattern. Some UAV spray systems are already in place and fixed with nozzles under the rotors. Those equipped with spray booms may have flexibility of adjustment. The optimum boom width requirements in UAV have not been established as it has been for manned aircraft. A general recommendation is that for a single rotor drone, boom length should be 80% or less of the rotor width. Extending the boom beyond the diameter of the rotor(s) or propeller to increase the swath can result in increased drift. The downwash of multirotor drones behaves differently from single rotor drone. Maintaining constant flight speed, altitude and swath width is necessary to achieve a uniform spray pattern. Comparisons of nozzles under rotors versus booms may be necessary.					X

Item		Requirement	Remarks	Type			
3. Machinery – Sprayer (depends on the test item) The sprayer should be a standard sprayer available on the market with a current state-of-the-art design. The application should be done in a typical local manner.				Minimum	Maximum	Mandatory	Request
3.8.1	Nozzle selection	Select common flat fan agricultural spray nozzles (*e.g.* TeeJet TT110-01). Nozzles of various orifice sizes to deliver **Fine, Medium or Coarse (and in cases for some herbicides, Very Coarse, Extremely Coarse and/ or Ultra Coarse)** spray qualities at pre-calibrated spray pressures according to ANSI/ASABE Standard S572.3 (Ref. 6.6).	Use of benchmark flat fan nozzles facilitates internal consistency, comparisons to other trials, and comparison to conventional application methods. Fine, Medium and Coarse spray qualities are expected to represent most agricultural applications, although others (including air induction nozzles) may be added or a subset of the three may be used in a particular individual study. If data are to be used for future label regulatory use, *e.g.* requiring on labels the use of a spray that is "Coarse or coarser", then the sprays should be on the boundary curves at the finest end of each droplet size category. In this example, the nozzle and pressure would be selected as one that delivers a droplet size spectrum on the ASABE reference boundary between Medium and Coarse. This assures that the highest possible drift is sampled for a "Coarse" spray. For some UAVs, utilizing nozzles other than what prescribed in the drone's software may compromise the application quality. Ensure compatibility between aircraft software and nozzle, if a nozzle different from what is on the aircraft spray system is used. Some UAVs use rotary atomizers below the rotors and no spray booms. These should be documented for rotation rate, flow rate and droplet size.			X	
3.8.2	Nozzle type	Select among available settings to deliver **Fine, Medium or Coarse** spray qualities for the selected nozzle type and orifice size according	Selection of an appropriate nozzle/pressure combination to deliver the desired spray quality must be determined and documented prior to testing. The nozzle selected to deliver the desired spray quality may be constrained by available pump settings and consequent spray pressures			X	

Item		Requirement	Remarks	Type			
3. Machinery – Sprayer (depends on the test item) The sprayer should be a standard sprayer available on the market with a current state-of-the-art design. The application should be done in a typical local manner.				Minimum	Maximum	Mandatory	Request
		to ANSI/ASABE Standard S572.3 (Ref. 6.6)	delivered by the UAV being used in the study. The pump flow rate influences the size of the nozzle that can be used and the ground speed. Many UAVs may have relatively low-capacity pumps. Verify the pump flow rate is adequate for the nozzle at the maximum speed that will be used. Given that the application speed is based on GPS-derived ground speed (not airspeed), the ambient wind speed and direction relative to flight direction affects the actual airspeed. Using measured flow rate and calculated pressure is an effective method to describe and assure the nozzle operating conditions. If data logging/transmission channel can be made available for use with a pressure transducer or flow meter and installed on an aircraft, that data could be stored as a data field in the application "as-applied" data.				
3.8.3	Nozzle size/orifice		Might be given by choice of machinery + manufacturer's recommendation Following local and machinery stand-ards as far as possible. Note: Depends on targeted pressure and application rate (and vice versa) as well as droplet size capabilities for the type of product being used (*e.g.,* coarser sprays for herbicides)			X	
3.8.4	Pressure at the nozzle (as deter-mined by flow rate)	Depends on nozzle type and size, speed, droplet spectrum (size) and tar-geted applica-tion volume	Might be given by choice of machinery + manufacturers' recommendation Following specific recommendations for the used nozzle + local and machinery standards as far as possible Depends on used nozzle size and application rate (and vice versa)			X	

Item		Requirement	Remarks	Type			
3. Machinery – Sprayer (depends on the test item) The sprayer should be a standard sprayer available on the market with a current state-of-the-art design. The application should be done in a typical local manner.				Minimum	Maximum	Mandatory	Request
3.8.5	Number and placement of nozzles	May vary	Manufacturer recommendations and those commonly applied to single-rotor or fixed wing airframes might not be optimal for UAV spraying. The optimum boom width requirements on UAVs have not been established as it has been for manned aircraft. A general recommendation is that for a single rotor drone, boom length should be 80% or less of the rotor width. Extending the boom beyond the diameter of the rotor(s) or propeller to increase the swath can result in increased drift. The downwash of multirotor drones behaves differently from single rotor drone. The standard experiment will include 4 nozzles placed symmetrically across the upwind/downwind axis of the UAV flying in a crosswind Under-rotor placement of 4 nozzles (two on each side) is a common configuration that may be tested. If nozzles are distributed across a spray boom (for example, 2 upwind and 2 downwind with respect to the line of flight), consideration must be given to the spacing needed to deliver a uniform in-swath spray deposition (see Table Section 3,Machinery – Sprayer (depends on the test item), part 3.2) as well as the alignment of each nozzle with proximal rotor tip vortices. Nozzle configuration and/or number of nozzles used may be a tested variable in some studies Document UAV dimensions as shown in figures located in Appendix 5.4.			X	

Item		Requirement	Remarks	Type			
3.	**Machinery – Sprayer (depends on the test item)** The sprayer should be a standard sprayer available on the market with a current state-of-the-art design. The application should be done in a typical local manner.			Minimum	Maximum	Mandatory	Request
3.9	Flight height (nozzle to ground or top of canopy depending on intended target) and height of particle release above ground and canopy	Target height of 3m as comparative standard across studies May vary; Could be dependent on outcome of swath width measurements	Other heights may be included for research/optimization purposes Method for how altitude is maintained during trial (*e.g.*, manual vs RTK (Real Time Kinematics) GPS (Global Positioning Satellites), Radar, LIDAR or other autonomous UAV) should be documented Distance to ground and top of crop need to be recorded. Also record if a crop such as trees or vines was being sprayed and if terrain following (radar) capability was being used			X	

Item		Requirement	Remarks	Type			
4.	**Machinery – Ground (tractor) Reference Sprayer (To be used as described)** The reference sprayer settings as described below should be maintained as close as possible in all trials such that it can be used to identify impact of environment (wind speed, temperature etc.), operational parameters (flight height, speed, nozzle type, droplet spectrum etc.) when changing UAV setup. Always make the application using the reference sprayer immediately after the UAV application. The ground reference sprayer will simulate as close as possible the droplet size spectrum delivered by the experimental UAV, the ground sprayer will use a horizontal boom with approximately the same swath width as that of the UAV. The time between the application with the UAV and the ground sprayer should be minimized as much as possible to avoid significant changes in weather conditions, ideally less than 15 minutes. The targeted water volume will be the lowest recommended for ground application (*i.e.*, as determined in product labels), this may be typically in the range of 100-200 L/ha.			Minimum	Maximum	Mandatory	Request
The machinery and its setup can be a matter of the initial trial question and thus may vary across or within a trial program. If comparing crops and/or growth stages: For every trial and every test run the same sprayer must be used.						X	
4.1	Sprayer type	Ground, tractor-driven boom sprayer	Acceptable sprayer: Tractor-mounted 3-point sprayers with boom, a power take-off (PTO) or electric pump, equipped with pressure gauge, in-line strainer, pressure relief regulator, and shut-off valve to control water flow to spray boom. A boom that can be used with multiple nozzle tips and a wingspan that can simulate that of the UAV. Pump capable of delivering the flow rate and pressure needed by the nozzles and boom length. Fully describe the spray system used.			X	
4.2	Working width (Swath width)	To match as close as possible that used for the UAV application	Similar to that of the UAV, swath width is impacted by nozzle type and spray pressure (flow rate), position and orientation of the nozzles on the boom, release height, ground speed, and environmental conditions. Use the same method used with the UAV to determine the effective spray width of the ground sprayer, at the predetermined boom height (tip of the nozzle to ground or top of canopy), ground speed and nozzle set up, and placing water sensitive	X	X		

Item		Requirement	Remarks	Type			
				Minimum	Maximum	Mandatory	Request

4. Machinery – Ground (tractor) Reference Sprayer (To be used as described)

The reference sprayer settings as described below should be maintained as close as possible in all trials such that it can be used to identify impact of environment (wind speed, temperature etc.), operational parameters (flight height, speed, nozzle type, droplet spectrum etc.) when changing UAV setup. Always make the application using the reference sprayer immediately after the UAV application.

The ground reference sprayer will simulate as close as possible the droplet size spectrum delivered by the experimental UAV, the ground sprayer will use a horizontal boom with approximately the same swath width as that of the UAV. The time between the application with the UAV and the ground sprayer should be minimized as much as possible to avoid significant changes in weather conditions, ideally less than 15 minutes.

The targeted water volume will be the lowest recommended for ground application (*i.e.*, as determined in product labels), this may be typically in the range of 100-200 L/ha.

Item		Requirement	Remarks	Minimum	Maximum	Mandatory	Request
			cards across the spray pass, avoiding placing cards on the tractor wheels track. See Appendix 5.5.2 for additional details on how to determine the working width for the ground sprayer				
4.3	Working (travel) speed	As required to deliver the pre-set water volume with selected nozzles and spray pressure, but not to exceed 25 km/hour	Calibrate speed using the tractor RPM. Mark out 100m, choose desired gear, and set the RPM on the hand throttle; travel and time how long it takes to cover 100m. Divide 100m by the seconds it took to travel 100m. Multiply by 3.6 to get kph (kilometers per hour). Repeat twice to get the average speed. Describe if using a different method.		X	X	
4.4	Agitation	Set to on if available	Describe the type of agitation system in the tank.			X	
4.5	Water (carrier) volume	Target range of 100 – 200 L/ha	Target a minimum volume of 100 L/ha and a maximum of 200 L/ha	X	X		
4.6	Calibration prior to trial	Spray rate, pressure Application speed, Effective working width Each nozzle should have its flow rate measured at each application	Follow established calibration methods for ground rigs, and document description of method used here. Outcome: Application rate per area unit (US GPA or L/ha)			X	

Item		Requirement	Remarks	Type			
4.	**Machinery – Ground (tractor) Reference Sprayer (To be used as described)** The reference sprayer settings as described below should be maintained as close as possible in all trials such that it can be used to identify impact of environment (wind speed, temperature etc.), operational parameters (flight height, speed, nozzle type, droplet spectrum etc.) when changing UAV setup. Always make the application using the reference sprayer immediately after the UAV application. The ground reference sprayer will simulate as close as possible the droplet size spectrum delivered by the experimental UAV, the ground sprayer will use a horizontal boom with approximately the same swath width as that of the UAV. The time between the application with the UAV and the ground sprayer should be minimized as much as possible to avoid significant changes in weather conditions, ideally less than 15 minutes. The targeted water volume will be the lowest recommended for ground application (*i.e.*, as determined in product labels), this may be typically in the range of 100-200 L/ha.			Minimum	Maximum	Mandatory	Request
		pressure					
4.7	Sprayer position and timing	GPS position of sprayer at time of application (to be recorded)	Data should be useful to assess the position of the sprayer and reference back to weather and other parameters				X
4.8	Nozzles & Boom	Document boom length.	Maintaining constant ground speed and boom height and swath width is necessary to achieve a uniform spray pattern.			X	

Item		Requirement	Remarks	Type			
4.	**Machinery – Ground (tractor) Reference Sprayer (To be used as described)** The reference sprayer settings as described below should be maintained as close as possible in all trials such that it can be used to identify impact of environment (wind speed, temperature etc.), operational parameters (flight height, speed, nozzle type, droplet spectrum etc.) when changing UAV setup. Always make the application using the reference sprayer immediately after the UAV application. The ground reference sprayer will simulate as close as possible the droplet size spectrum delivered by the experimental UAV, the ground sprayer will use a horizontal boom with approximately the same swath width as that of the UAV. The time between the application with the UAV and the ground sprayer should be minimized as much as possible to avoid significant changes in weather conditions, ideally less than 15 minutes. The targeted water volume will be the lowest recommended for ground application (*i.e.*, as determined in product labels), this may be typically in the range of 100-200 L/ha.			Minimum	Maximum	Mandatory	Request
4.8.1	Nozzle selection	Select common flat fan agricultural spray nozzles (*e.g.,* TeeJet TT110-01). Nozzles of various orifice sizes to deliver **Fine, Medium or Coarse (and in cases for some herbicides, Very Coarse, Extremely Coarse and/ or Ultra Coarse)** spray qualities at pre-calibrated spray pressures according to ANSI/ASABE Standard S572.3 (Ref. 6.6)	Use of benchmark flat fan nozzles facilitates internal consistency, comparisons to other trials, and comparison to conventional application methods. Fine, Medium and Coarse spray qualities are expected to represent most agricultural applications, although others (including air induction nozzles) may be added or a subset of the three may be used in a particular individual study. If data are to be used for future label regulatory use, *e.g.* requiring on labels the use of a spray that is “Coarse or coarser”, then the sprays should be on the boundary curves at the finest end of each droplet size category. In this example, the nozzle and pressure would be selected as one that delivers a droplet size spectrum on the ASABE reference boundary between Medium and Coarse. This assures that the highest possible drift is sampled for a “Coarse” spray. Selected nozzle should deliver a similar droplet size distribution as that selected for the UAV			X	

Item		Requirement	Remarks	Type			
4.	**Machinery – Ground (tractor) Reference Sprayer (To be used as described)** The reference sprayer settings as described below should be maintained as close as possible in all trials such that it can be used to identify impact of environment (wind speed, temperature etc.), operational parameters (flight height, speed, nozzle type, droplet spectrum etc.) when changing UAV setup. Always make the application using the reference sprayer immediately after the UAV application. The ground reference sprayer will simulate as close as possible the droplet size spectrum delivered by the experimental UAV, the ground sprayer will use a horizontal boom with approximately the same swath width as that of the UAV. The time between the application with the UAV and the ground sprayer should be minimized as much as possible to avoid significant changes in weather conditions, ideally less than 15 minutes. The targeted water volume will be the lowest recommended for ground application (*i.e.*, as determined in product labels), this may be typically in the range of 100-200 L/ha.			Minimum	Maximum	Mandatory	Request
4.8.2	Nozzle type	Select among available settings to deliver **Fine, Medium or Coarse** spray qualities for the selected nozzle type and orifice size according to ANSI/ASABE Standard S572.3 (Ref. 6.6)	Select nozzle that will deliver the flow rate that provides a similar spray droplet distribution as that of the UAV, taking into account the differences in spray pressure, water volume, speed and other factors unique to the ground sprayer			X	
4.8.3	Nozzle size/orifice		See above, provide nozzle description			X	
4.8.4	Pressure at the nozzle	Record pressure as indicated by pressure gauge	Use pressure recommended by nozzle			X	
4.8.5	Number and placement of nozzles	May vary	Document number and placement of the nozzles on boom			X	

Item		Requirement	Remarks	Type			
				Minimum	Maximum	Mandatory	Request
4.	**Machinery – Ground (tractor) Reference Sprayer (To be used as described)** The reference sprayer settings as described below should be maintained as close as possible in all trials such that it can be used to identify impact of environment (wind speed, temperature etc.), operational parameters (flight height, speed, nozzle type, droplet spectrum etc.) when changing UAV setup. Always make the application using the reference sprayer immediately after the UAV application. The ground reference sprayer will simulate as close as possible the droplet size spectrum delivered by the experimental UAV, the ground sprayer will use a horizontal boom with approximately the same swath width as that of the UAV. The time between the application with the UAV and the ground sprayer should be minimized as much as possible to avoid significant changes in weather conditions, ideally less than 15 minutes. The targeted water volume will be the lowest recommended for ground application (*i.e.*, as determined in product labels), this may be typically in the range of 100-200 L/ha.						
4.9	Boom height (nozzle to ground or top of canopy)	Select a commonly used boom height(such as 0.5 m): consult with test coordinator to confirm	Distance from nozzle to ground and top of crop need to be recorded. This does not apply to a crop such as trees or vines where a different reference sprayer will be used			X	

Item	Requirement	Remarks	Type: Minimum	Type: Maximum	Type: Mandatory	Type: Request
5. Drift measurement – Sampler Section differs significantly with Occupational-Residential-Exposure (ORE) trials, see also example layouts in Section 3.						
All distances are referring to the zero line, which is the exact downwind edge of the field (EoF) the sprayer is operated at (sprayed area), applies also when an in-crop buffer is used.					X	
5.1 Type of measurement	Ground (horizonal/ deposition)	Ground measurement must be included			X	
	Airborne (3D; vertical/ interception)	Airborne measurement may be included				X
5.2 Number of sampler types per distance and drift line	1	For each type of measurement	X			
5.3 Sampler type(s) => Ground	A flat sample collector (*e.g.*, mylar cards) is recommended. A sampler of choice can be used, but if a flat collector is not used, at least one drift line of the ≥3 (preferably more) must have a flat collector paired to each sampler in that line to serve as reference samplers.	The same sampler type should be used for both UAV and reference sprayer applications. Minimum surface area of sampler of choice is 100 cm^2 (*e.g.*, a 4”x4” flat surface collector). For samplers other than plastic cards, testing must be carried out to make sure there is no chemical binding to the collector. ALL samplers to be uniquely labelled (x,y coordinates in sampling area: *e.g.*, “Line 1; 3 m”). Candidate and blank collector controls should be subject to analysis to confirm absence of, or any detection of, background tracer or test article presence. It is further recommended that pre-dosed/spiked collectors are placed out in the field at the same time and near other collectors to provide further useful confirmatory information on performance. If the surface is cropped, samplers should be placed level with crop canopy to avoid losses due to			X	

Item		Requirement	Remarks	Type			
5.	**Drift measurement – Sampler** Section differs significantly with Occupational-Residential-Exposure (ORE) trials, see also example layouts in Section 3.			Minimum	Maximum	Mandatory	Request
			interception				
5.4	Repetitions of drift lines – Ground	≥3	See Table Section 1 (Repetitions and Replicates), part 1.2 Add an extra drift line if a flat collector is not the main sampler. Flat collectors are then placed next to each sampler of one drift line. Separate drift lines by approximately 4 m	X			
5.5	Number of distances along drift line– Ground	≥10 downwind ≥1 upwind ≥5 in swath	See Table Section 1 (Repetitions and Replicates), part 1.3	X			
5.6	Closest sampling point – Ground	1 m	See Table Section 1 (Repetitions and Replicates), part 1.4		X		
5.7	Furthest sampling point – Ground	200 m	See Table Section 1 (Repetitions and Replicates), part 1.5	X			
5.8	Distance between ground and airborne samplers	4 m	No specific value is given, yet a distance must be chosen at which no interference across sampling types is expected, assuming a wind direction tolerance of ±30° Additionally, it must be ensured that at time of sample collection there is no cross-contamination between airborne and ground samplers. Distance and calculation must be reported	X			

Item		Requirement	Remarks	Type			
5. Drift measurement – Sampler Section differs significantly with Occupational-Residential-Exposure (ORE) trials, see also example layouts in Section 3.				Minimum	Maximum	Mandatory	Request
5.9	Sampler type(s) => Airborne (3D)	Sampler of choice, but a sampler with known sampling area or known collection efficiency/sampling rate (for active samplers like vacuum sampler or spinning impingers), must be used	Collectors with high and known passive capture/ collection efficiency and known surface area, for example nylon strings. Other types (*e.g.,* active sampling devices) may be added. In some cases, 3D LiDAR may also be used as a potential alternative for plume detection and movement/deposition.				X
5.10	Replication of drift lines – Airborne (3D)	≥3	= How often the sampler is placed at every distance-height combination used Suggestion: 3 as a minimum when using the trial within registrations or to allow statistical purposes	X			
5.11	Distances the samplers are placed at – Airborne (3D)	1	According to local needs/discussion If only 1 distance is used 1 m which is the minimum distance for ground drift sampling.	X			
5.12	Number of heights the airborne samplers are placed at	3	With the lowest at 1 m maximum above ground and the upper one at least 2 m above flight height Only one tower should be used to hold all heights per airborne measuring point	X			

Item		Requirement	Remarks	Type			
5. Drift measurement – Sampler Section differs significantly with Occupational-Residential-Exposure (ORE) trials, see also example layouts in Section 3.				Minimum	Maximum	Mandatory	Request
5.13	Sampler collection timing	5 – 15 min	No less than 5 minutes for most studies and no more than 15 minutes after application. Be certain that the spray drift has had time to reach the furthest collectors which will depend on droplet size, release height, wind speed, etc. Start at distance furthest away from zero line to minimize risk of contamination from other samplers Document sample collection method, including start and end of sampling events Store the collected samplers into a cooler with some ice packs while in-field. Keep refrigerated until analysis in lab. It is also recommended to get information regarding stability, recovery and extractability of the tracer used to make decision on sampler collection timing.	X	X		
5.14	In-field verification (within swath deposition)	A sampler (mylar cards, petri dish etc.) every 0.25 m within the anticipated swath in one line split across the treatment area; replicated ≥3 times; a minimum of 5 m buffer required between replicates.	If utilized = Additional samplers laid out within the sprayed area Note: results could explain variations in data captured in measurement area, yet variations might be expected with some UAVs being commercially available				X

Item		Requirement	Remarks	Type			
6.	**Spray liquid** Selection of the test item should be done under consideration and according to the local availabilities and trial question. Either a tracer/dye or product (depending on local regulatory environment) can be used.			Minimum	Maximum	Mandatory	Request
6.1	Application rate (mixture)	May vary	To be selected for any trial individually, typical rates used with UAVs are 3-30 L/ha When comparing UAVs, a common application rate could be used to reduce the number of test variables, yet some UAVs have a certain range they are intended to be used with Function of nozzle, pressure (including pump limitations), and forward speed as outlined above Measurement of the amount mixed/added to the tank and the amount left after the trial (to monitor the application rate together with sprayed area). Tank mix samples should be measured before and after spraying			X	
6.2	Tracer					X	
6.3	Tracer – Test item	Tracer of choice	= analyte Tracer must be used if an active ingredient is not specifically required or permitted. In general, for simplicity, tests may be conducted with tracer alone. However, where warranted, PPP and tracers can be combined subject to consideration. This should not disrupt stability or create analytical interference. Supplementary confirmatory checks are warranted to address this. If tracers are to be used in conjunction with active ingredient(s) there is an additional necessity to consider compatibility, stability and analytical interference. Employment of tracers alongside tank mixes necessitates further consideration of compatibility because of the wider range of tank mix components. If evaluating technologies in a generic approach, only tracers (*e.g.*, not active			X	

Item		Requirement	Remarks	Type			
6. Spray liquid Selection of the test item should be done under consideration and according to the local availabilities and trial question. Either a tracer/dye or product (depending on local regulatory environment) can be used.				Minimum	Maximum	Mandatory	Request
			ingredient) should be used.				
6.3.1	Tracer – Type *if used*	Tracer of choice	Must be water-soluble, non-volatile. and photostable for the duration of open storage prior to dark storage and/or analysis Tracer employed can be drawn from examples in Section 4 and Ref. 6.3 or examples reliably used at institute conducting study where there is photostability evidence to support this choice.			X	
6.3.2	Tracer – Concentration *if used*		Sufficiently high to reach 10 x LOQ at maximum distance for the experiment (LOQ = Limit of Quantitation) Resolution required at the furthest distance to be able to separate out the variables in the trial. Depends on collector efficiency, equipment and tracer used. It is noted that this is a matter of expert judgment based on the trialists' understanding and experience. In general, experience suggests that 0.5 – 2 g tracer per L of tank mix is generally sufficient to address requirements for robust quantification but there is acknowledgment that this depends upon the tracer and detection limits			X	

Item	Requirement	Remarks	Type			
6. Spray liquid Selection of the test item should be done under consideration and according to the local availabilities and trial question. Either a tracer/dye or product (depending on local regulatory environment) can be used.			Minimum	Maximum	Mandatory	Request
6.3.3 Photostability check		Initial checks must be made to verify the performance of the tracer dye with the collectors to be used Photostability must also be checked at the time of the trial. Tracer must exhibit adequate photostability (documented or published). It is recommended that stability is demonstrated on the basis that all samples are within 10% of the initial mixture detection values (note that this recommendation is consistent with US EPA Protocol for Testing Pesticide Application Spray Drift Reduction Technologies, Ref. 6.4). It is particularly stressed that any tracer photostability vulnerability necessitates particular care and attention with timely collection of samplers and prompt sampler storage to maintain data integrity. See also Section 4.			X	
6.4 Tank sample	Taken once per mixture used	Tank sample taken from nozzle(s). Take one sample prior to application and sample after application to verify photostability for the duration of testing. Additional tank mix samples should be taken to assure adequate agitation and, if multiple tank loads are used in experiment, sample to assure that each mix is correct			X	

Item		Requirement	Remarks	Type			
6. Spray liquid Selection of the test item should be done under consideration and according to the local availabilities and trial question. Either a tracer/dye or product (depending on local regulatory environment) can be used.				Minimum	Maximum	Mandatory	Request
6.5	Plant Protection Products *if used*	Generally – None Only if Specifically needed for a product registration or such	The recommendation for the current research phase is to use tracer as the test item If an active ingredient is the test item instead of a tracer: Analytical procedure must be documented, including method validation procedures. Study conduct should consider necessity to characterize stability (photostability and storage stability). Typically, issues with stability will be known from preceding efficacy testing. Confirmatory statements regarding consideration of stability (photostability and storage stability) should be included in study methodology. If active ingredient is used, all label instructions (PPE, REI, PHI, posting, local regulations) must be followed. If non-label use is investigated, proper handling of crop, including destruction, must be followed.”				X
6.6	Adjuvants	None	Includes surfactants if necessary Except surfactants, which may be part of the formulation of the tracer or the active ingredient mixture (such as with a formulated plant protection product). If surfactant is included in spray liquid in a trial, it should be exactly as proposed for use in plant protection product. As noted in Section 6.3, if tracers are to be used in conjunction with active ingredient(s) there is an additional necessity to consider compatibility, stability and analytical interference. Employment of tracers alongside tank mixes necessitates further consideration of compatibility because of the wider range of tank mix components.				X

Item		Requirement	Remarks	Type			
7.	**Weather Recording** Record measurements of weather, including wind speed and direction, covering the test site (treatment area and sampling area used to derive drift data).			Minimum	Maximum	Mandatory	Request
7.1	Weather station – placement		Within the crop canopy, upwind of the sprayed area, on the centerline of the sampling area. Refer to Figure 2. If a second weather station is available, place it downwind beyond the sampling area on the center line of the sampling area. Ensure weather conditions are compliant with any local, state/provincial, or federal requirements for UAV operations.			X	
7.2	Multiple weather stations	Two weather stations are preferred	If a second weather station is available, it should match the first one with its specifications and settings. At a minimum, wind direction, speed, and air temperature should be measured at two heights				X
7.3	Target wind direction at application	Nominally 90° angle to the direction of spray path	Relates to mean values during spraying The maximum deviation of 30° to both sides			X	
7.4	Wind direction measurement - Height	Two heights	Measurement at two heights is required, preferably at aircraft release (*e.g.*, nozzle) height and reference sprayer release (*e.g.*, nozzle) height. Where a reference sprayer is not used, the second height may be at crop height.		X		
7.5	Targeted average wind speed over the trial	2.0 to 5.0 m/s	Relates to mean values during spraying. Refer to Ref. 6.2.	X	X		
7.6	Wind speed measurement method	Either: a) Ultrasonic anemometers b) Cup anemometers	Ideally, continuous recording throughout the trial (Recording frequency: 1 Hz) Ultrasonic anemometers are preferred.			X	

Item		Requirement	Remarks	Type			
7.	**Weather Recording** Record measurements of weather, including wind speed and direction, covering the test site (treatment area and sampling area used to derive drift data).			Minimum	Maximum	Mandatory	Request
7.7	Wind speed measure-ment - Height	Two heights	Measurement at two heights is required, preferably at aircraft release (*e.g.*, nozzle) height and reference sprayer release (*e.g.*, nozzle) height. Where a reference sprayer is not used, the second height may be at crop height.		X		
7.8	Temperature	Ideally 5 to 30 °C	Temperature recording is mandatory for trial. Recording: Ideally, continuous recording throughout the trial, but at minimum once per test run and Min/Max of the trial day Measurement at two heights is required, preferably at aircraft release (*e.g.*, nozzle) height and reference sprayer release (*e.g.*, nozzle) height. Where a reference sprayer is not used, the second height may be at crop height. **Note: Temperature inversions should be avoided.**			X	
7.9	Humidity	Ideally 20 to 90%	Humidity recording is mandatory for trial. Recording: Ideally, continuous recording throughout the trial, but at minimum once per test run and Min/Max of trial day			X	
7.10	Archiving of weather data		All raw weather data (wind speed, wind direction, temperature, humidity) needs to be archived in full (*e.g.*, not just the averages recorded)			X	

Item		Requirement	Remarks	Type			
8.	**Analytical work**			Minimum	Maximum	Mandatory	Request
8.1	Analytical system		The laboratory may choose its preferred analytical system that is able to quantitate the specific tracer dye (or active ingredient) used. Must be a quantitative measurement reported against a relevant calibration curve.			X	
8.2	Limit of Quantification (LOQ)		LOQ must be determined and reported using any accepted method established at the analyzing laboratory for the specific analysis being conducted. Analytical procedures should also characterize extractability/recovery of tracer or test items selected for assessment associated with the chosen collector system.			X	
8.3	Photostability check		Checked in the field at the time of the trial Refer to SETAC DRAW in Section 4 and Ref. 6.3.				
8.4	Controls		Where a single site is used for numerous trials it is recommended that background levels for tracer and/or test article should be confirmed through analysis of periodic field collector blanks prior and after trials.			X	
8.5	Format and content of reports		The measured ground and airborne spray drift mass of the tracer dye (or active ingredient) measured at each sampling position (including in-swath measurements) must be reported The result from each sample location will be a 'mean spray drift deposit level' expressed as a percentage of the actual observed application rate from in-swath sample collection.			X	

Item		Requirement	Remarks	Type			
9.	**Any other**			Minimum	Maximum	Mandatory	Request
9.1	Staff	Assignment of key roles, team selection, and responsibilities	A person operating the sprayer who cannot collect samples Ideally, one person is present only to run the weather station and to document and photo-document (footage) the trial If feasible, teams can be selected: - Team for laying out samples and collecting in swath and near field samples (with frequent changes of gloves etc.) - Team for laying out and collecting far field drift samples (with frequent changes of gloves etc.) - Team for mixing, application, and recording	X			
9.2	Video and/ or photo record-ing		Where possible, record via video and/or photograph spray events periodically. Generally available digital standards (*e.g.*, MPEG 4) should be used. Useful for assessing drift trial dif-ferences later				X
9.3	Exact record-ing		As a minimum, flight times for each spray event should be rec-orded. This information will be used to match with logged weather data. Imaging and recordings should not be taken at or near locations deemed sensitive by local, state/provincial, or federal agen-cies.			X	
9.4	Data Storage		All data, images, video recordings, field notebooks, reports, etc. should be appropriately stored			X	

Item		Requirement	Remarks	Type			
9.	**Any other**			Minimum	Maximum	Mandatory	Request
			with adequate security to prevent unintended loss, corruption, or transfer of information.				
9.5	Units of measurement		Reported measurements should be presented in the International System of Units (SI).			X	

3. Figures and layout of trial design

The following figures visualize the requirements listed above. However, these figures are not to scale and do not show every detail. It is recommended to create similar figures for every specific drift trial planned.

All drawings are designed to visualize potential setups—a specific trial layout may vary, especially with regard to distances selected and required. All test trial designs should be fully documented.

Figure 1: Trial site with 'Treatment area' and 'Measurement area'

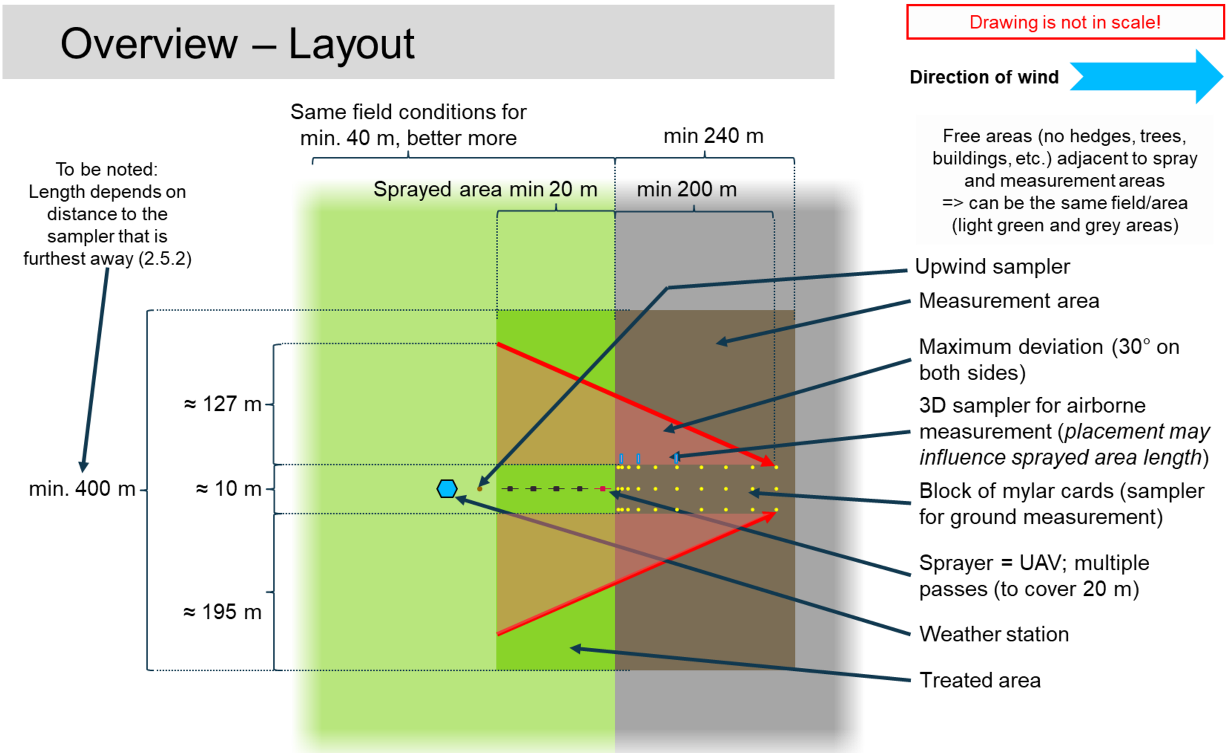


Figure 2: Overall layout of the trial; including dimensions of area accounting for wind divergence of 30°.

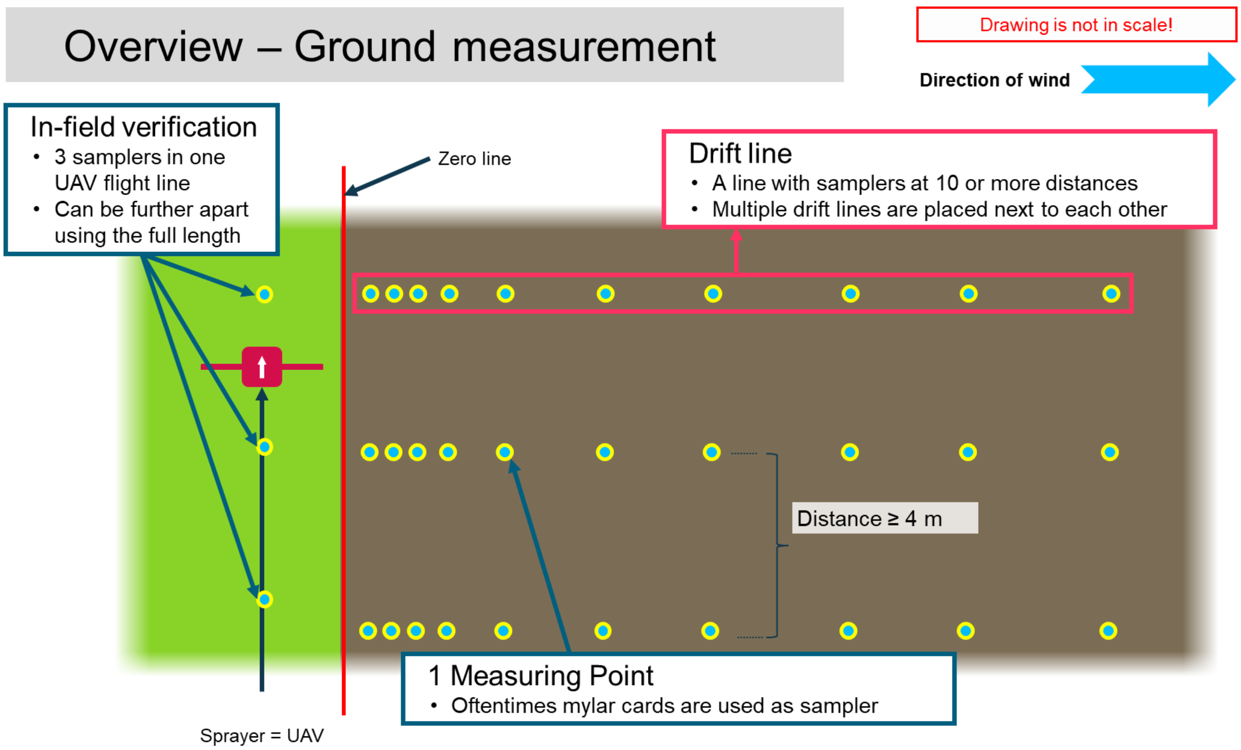


Figure 3: **At least three drift lines, each of which with ten sampling distances, building up one block of samplers for measuring ground deposition.**

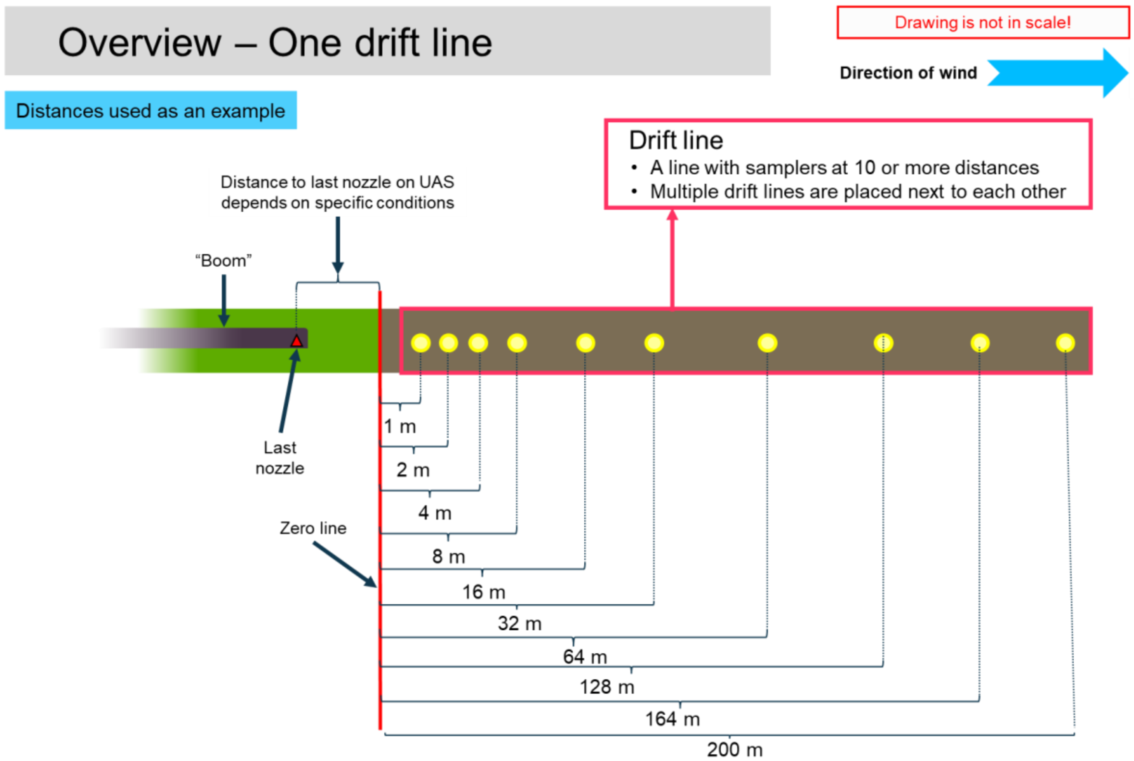


Figure 4: **Detailed layout of one drift line and its measuring points (same sampler at different distances) for ground deposition. Distances as a recommendation can be changed and/or sample distances added (200 m is the recommended minimum).**

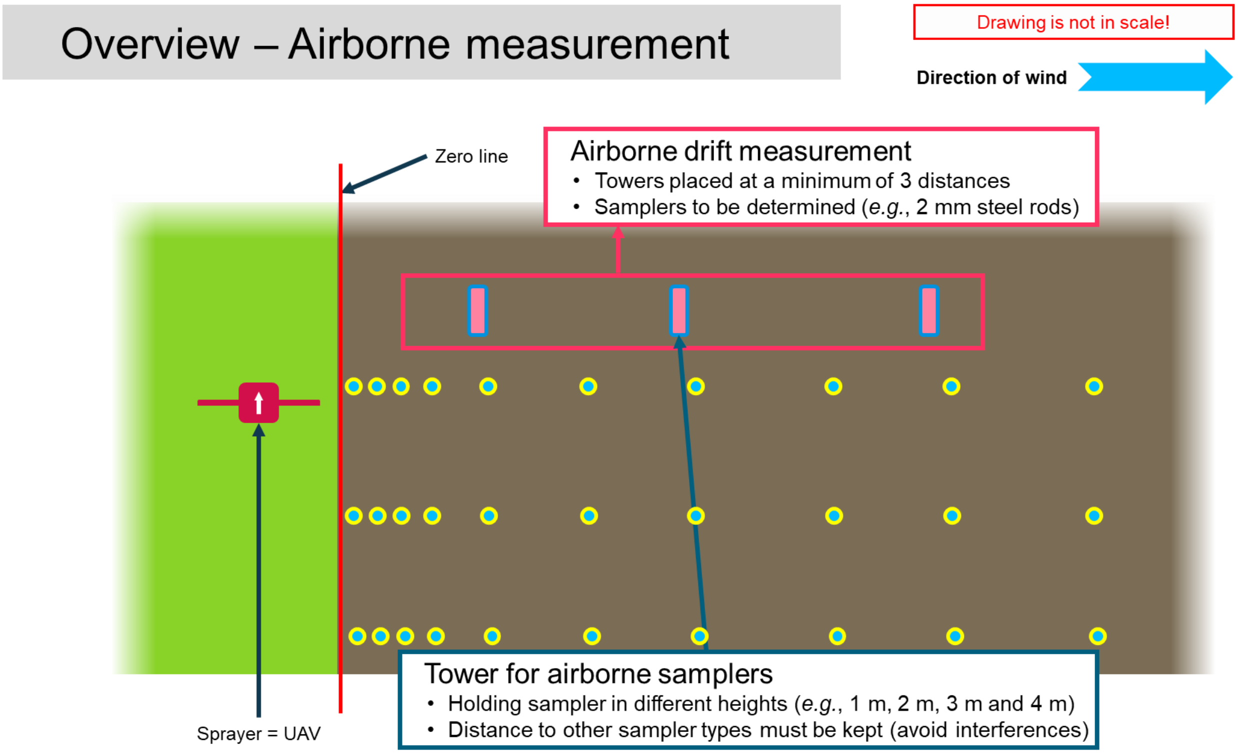


Figure 5: **Sampling area with added setup for airborne measurement. Distance to the block of mylar cards needs to be kept, distance needs to be calculated/judged individually. See Appendix 5.2 for examples of towers to hold samplers (a minimum of three is suggested).**

4. Photostability check

In the Requirements Table, part 6.3.1, it is noted that tracer dye must be water-soluble, non-volatile and photostable. Examples of photostability characterization assessments that can be conducted to assist in choice of, and characterization of, dye tracers are summarized in a range of publications[1]. It is noted that these publications also provide background on a range of dye tracers that have been characterized and could be considered to support assessments. These include:

- Pyranine (Nairn and Forster, 2015)
- BSF (Brilliant Sulfaflavine; Sheng-Suan and Stark, 1997)
- Tartrazine and Amaranthus (Gubiani, Pergher and Zucchiatti, 2021)
- PYRENE TETRA SULFONIC ACID TETRA SODIUM SALT (PTSA; Hoffmann, Fritz and Ledebuhr, 2014)

It is noted that individual research institutes have experience with a range of dye-tracers with some institute/organisation preferences noted below (Personal Communication, N. Mackay, 2021):

- Agrimetrix, Canada: *Rhodamine WT, sodium fluorescein*
- Plant Research International, The Netherlands; BSF, *Acid Yellow 250 / Brilliant Yellow 8G-R*
- *SSAU, UK; Green S* (*E1*42) and fluorescein sodium salt

Further background on evaluation strategy is available in recommended papers[2].

For in-field tests, US EPA offers the following general guidance[3];
"Stability of tracer under conditions of study (light intensity, relative humidity, temperature, sampling media, storage conditions/duration) measured as the amount recovered relative to the amount mixed for control sample. Tracers must exhibit adequate photostability (documented or published) allowing within 10% of the initial mixture detection values for all samples (note: samples should be collected in minimum possible time after exposure to drift sampling, stored in dark containers and analysed as soon as possible after collection)."

[1] Photostability characterization publications:
Sheng-Suan Cai & John D. Stark (1997) Evaluation of five fluorescent dyes and triethyl phosphate as atmospheric tracers of agricultural sprays, Journal of Environmental Science and Health, Part B, 32:6, 969-983
R. Gubiani, G. Pergher and N. Zucchiatti, "Evaluation of Tracer dyes for spray deposit assessment in the vineyard," *2021 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor)*, 2021, pp. 460-465
J.J. Nairn, W.A. Forster (2015) Photostability of pyranine and suitability as a spray drift tracer, *New Zealand Plant Protection 68: 32-37*

[2] Recommended papers for background
Hall, F.R., Kirchner, L.M., Downer, R.A. (1993) Some Practical Limitations of Fluorescent Tracers Used to Measure Off-Target Pesticide Deposition, Symposium Paper **STP20198S in Pesticide Formulations and Application Systems Vol. 12, Ed P.D. Berger, ASTM; https://www.astm.org/stp20198s.html**
Downer, R.A., Kirchner, L.M., Hall, (1997) Comparison of Droplet Spectra of Fluorescent Tracers Commonly used to Measure Pesticide Deposition and Drift, Symposium Paper STP13837S in Pesticide Formulations and Application Systems: 17th Volume, Editor(s): HM Collins; ASTM; Comparison of Droplet Spectra of Fluorescent Tracers Commonly used to Measure Pesticide Deposition and Drift (astm.org)

[3] USEPA (2016) Final Generic Verification Protocol. For the verification of pesticide spray drift reduction technologies for row and field crops; https://www.epa.gov/reducing-pesticide-drift/generic-verification-protocol-testing-pesticide-application-spray-drift

Taking into consideration this guidance, the following recommendation is made based upon the SETAC DRAW Protocol for Drift Trial:

Initial checks must be made to verify the performance of the tracer dye with the collectors to be used so that batches that may have limitations regarding photostability are identified. This can utilize any accepted method established at the laboratory.

Photostability must also be checked at the time of the trial. This will involve putting out collectors with a known applied dose that are then exposed for the period when the application is made, and the samples collected. Photostability checks should also take into consideration more fundamental dark storage stability by including test controls. This can be done using any documented and validated approach used at the laboratory.

As a minimum, three pairs of collectors can be placed under the sprayer (aligned fore and aft) such that they are sprayed with the first pass of the sprayer. When sprayed, both collectors in each pair are removed from the swath – one is then covered and stored in a cool dark place whereas the other is exposed in the same manner as for the collectors used in the trial. The collectors are then analysed as pairs with the results for the exposed and covered collectors compared to give an estimate of photodegradation.

Note: Text adapted from SETAC DRAW Protocol for Drift Trial (Ref. 6.3).

5. Appendices

5.1 Layout including samplers used in Occupational-Residential-Exposure (ORE) trials

Trials tailored to generate data sets to fulfill Occupational-Residential-Exposure (ORE) risk assessment requirements differ significantly to those trials focused on sedimental and airborne drift. It should always be considered and discussed to include various drift aspects once setting up a trial, and thus an evaluation whether ORE specific requirements can be added should be undertaken (or vice versa).

An example of a trial setup with added ORE samplers (*e.g.,* mannequins of large and small size) is given below.

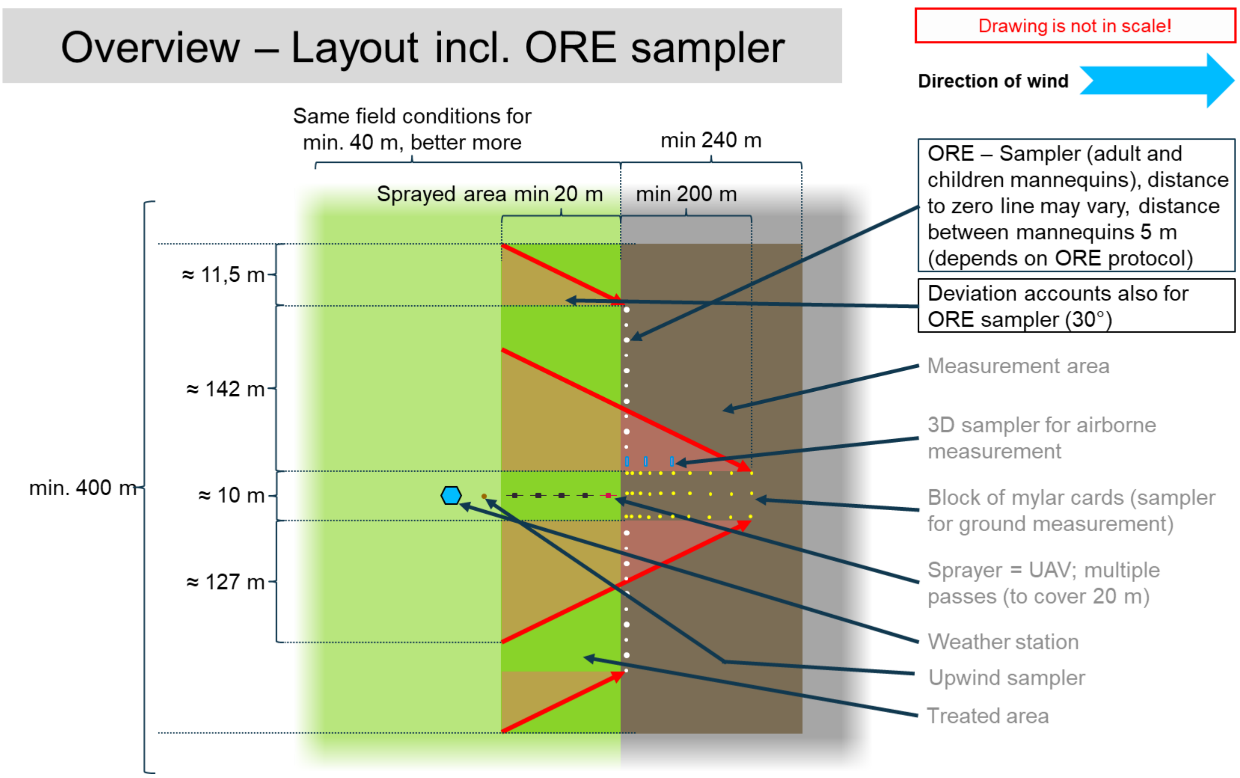


Figure 6: Overall layout of the trial; including dimensions of area accounting for wind divergence of 30° when also implementing ORE samplers (2 different sized mannequins, 10 each).

5.2 Ideas for holder for sampler, ground as well as airborne.

In order to conduct as many flights (individual treatments) as possible, it is of great advantage to have specially designed and built holders in place allowing a relatively fast and, more importantly, exact placement of samplers across spray applications/repetitions.

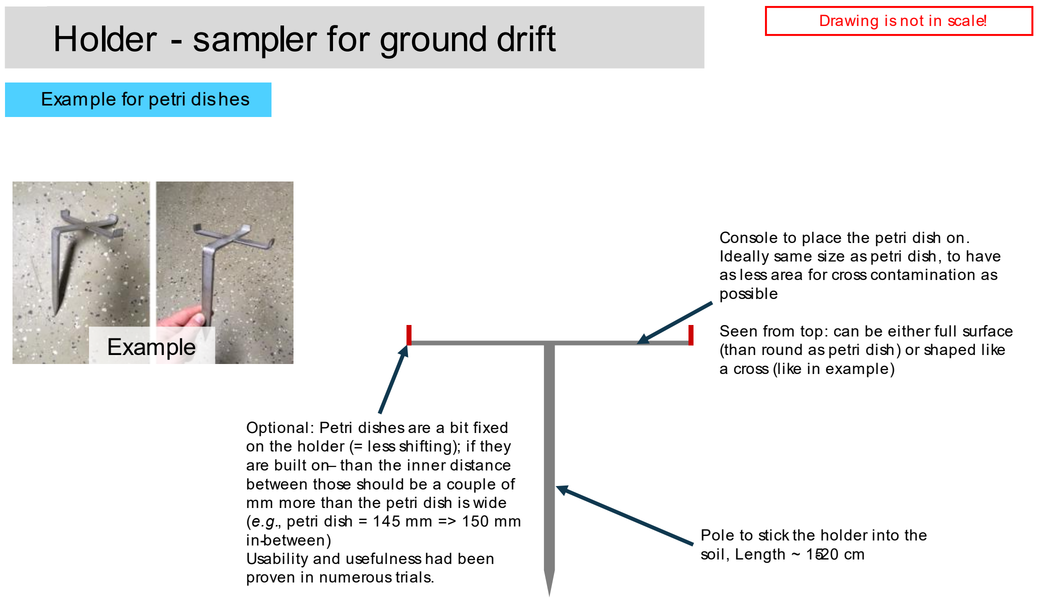


Figure 7: Holder - sampler for ground drift

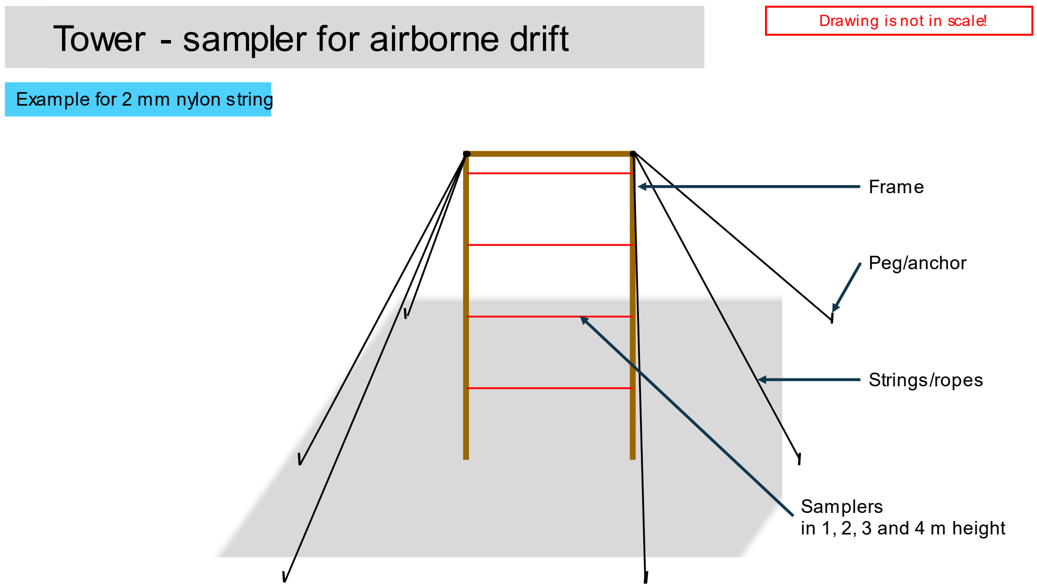


Figure 8: Holder - sampler for airborne drift // Potential layout for 2 mm nylon strings of 1 m length

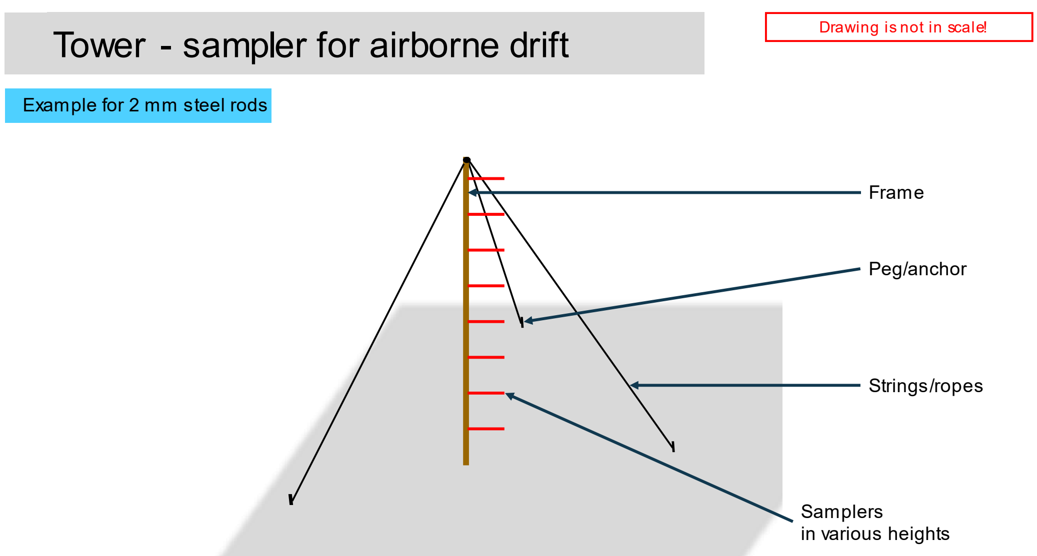


Figure 9: Holder - sampler for airborne drift // Potential layout for 2 mm steel rods of 20 cm length

5.3 EFSA reporting acceptance criteria

1. A clear description of the methodology is given and justified

2. Drift must be directly linked to a plant protection substance application event via a realistic experimental study.

3. The aims, objectives and context are clearly stated and appropriate to the study

4. The sampling approach is clearly described and is justifiable, representative and appropriate, and allows for a consistent sample to be collected. As a minimum this must include sampling time, sampling interval, distance from application to sampling point, sampler type/collector, sampler height.

5. Sampling surfaces/collectors should be adequately sized and spatially distributed. There should be at least 3 sampling points per site.

6. The test site should be clearly defined. This should include the location where the experiment was conducted, positioning of sampling points and time of year. It should also include information on site topography *e.g.*, slope and any obstructions to air flow.

7. Key experimental data must be reported. As a minimum this should be identification of the PPP, formulation, composition, application rate and crop. If a named commercial product is used the concentration in the product should also be reported.

8. Key equipment information must be provided. As a minimum this must include sprayer type, nozzle type, pressure, and if any drift reduction technologies have been used.

9. The meteorological conditions must be fully reported. As a minimum this must include temperature, humidity & wind speed.

10. Rainfall, sunshine/cloud, wind direction would be desirable.

11. Measurements should be replicated under conditions as similar as can be reasonably expected. A minimum of 2 replicates are required.

12. Statistical analysis is appropriate and must address the variability of the study results.

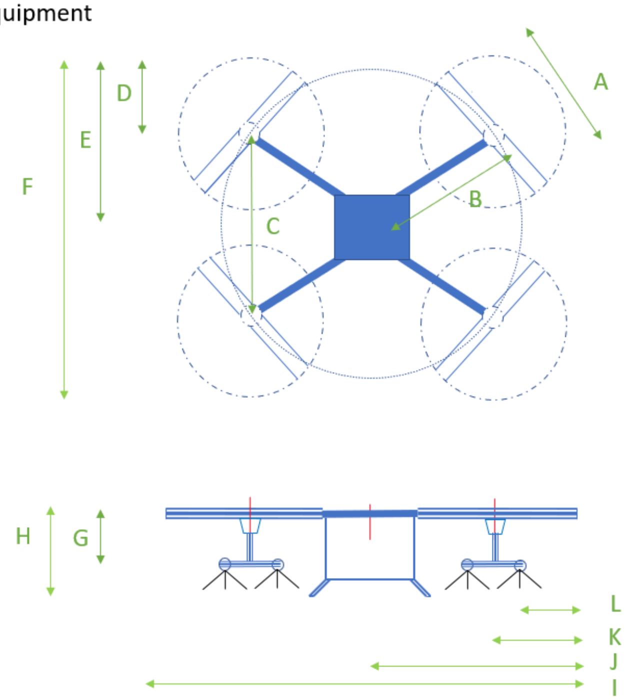
13. Laboratory / analytical work should be done using a validated technique. LOQ / LOD should be reported or identifiable from elsewhere.

14. If a surrogate is used instead of a pesticide the compound must be clearly identifiable. A clear description of the methodology is given and justified

5.4 Multi-rotor UAV dimensions need to be documented as shown in the figures below. Dimensions for other UAV designs (single rotor, fixed wing, etc.) should be recorded in a similar manner.

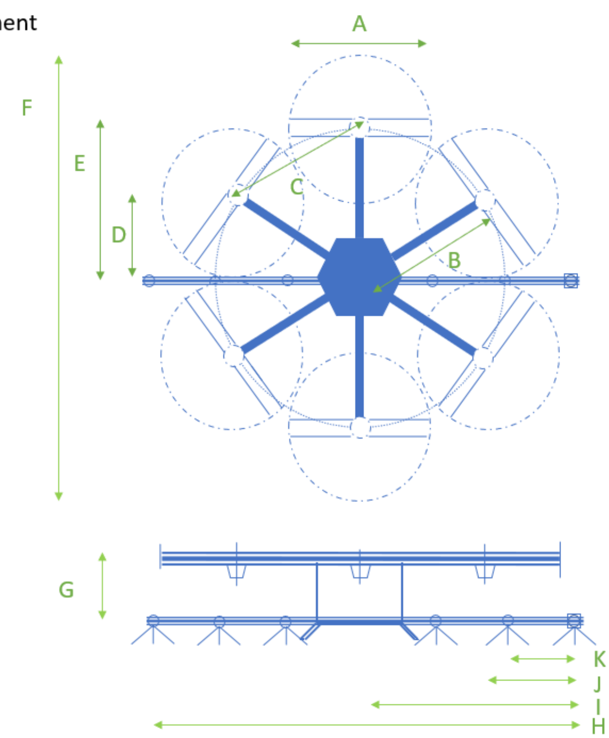
Aircraft Dimensions Related to the Application Equipment

1. Number of Rotors-
2. Number of Nozzles-
3. A-Rotor Diameter -cm
4. B-Rotor arm -cm
5. C-Rotor to Rotor -cm
6. D-Rotor radius -cm
7. E-Center line -cm
8. F-Rotor tip to rotor tip -cm
9. G-Rotor to nozzle tip -cm
10. H-Rotor to landing struts -cm
11. I-Rotor tip to rotor tip -cm
12. J-Outside rotor tip to center -cm
13. K-Rotor tip to boom center -cm
14. L-Rotor tip to nozzle tip - cm



Aircraft Dimensions Related to the Application Equipment

1. Number of Rotors-
2. Number of Nozzles-
3. A-Rotor diameter -cm
4. B-Rotor arm -cm
5. C-Rotor to rotor -cm
6. D-Rotor to boom -cm
7. E-Rotor center to boom -cm
8. F-Rotor tip to rotor tip -cm
9. G-Rotor to boom -cm
10. H-Boom length -cm
11. I-Boom end to center -cm
12. J-Boom end to rotor center -cm
13. K-Nozzle center spacing -cm



5.5 Working width (Effective swath width)

5.5.1 UAV

Swath width is impacted by nozzle type and spray pressure (flow rate), position and orientation of the nozzles (under-rotor or on a boom), release height, flight speed, size of the UAV, and environmental conditions. There are multiple ways to determine the effective swath width, one way is by flying the UAV while spraying at the predetermined flight height, speed, and nozzle set up, and placing water-sensitive cards or other deposition samplers (*e.g.*, mylar cards) across the flight pass. Cards can be placed across the manufacturer-provided width, allowing for 50% extra on each side, for example, if the spray swath width provided by the manufacturer is 4 m, place cards across 8 m (4 * 0.5 = 2 m extra on each side). Cards can be spaced every 25 cm. During low wind conditions or flying into either a headwind or tailwind if the wind is >5 mph (or >8 km/h), spray over the cards at the flight parameters above, and allow for 20 m of spray before the UAV reaches the position of the cards and another 20 m of spraying after flying over the cards. Repeat with clean cards at least three times. Get coverage data on the individual cards (using scanner and software, *i.e.*, Snapguard, or Deposit scan DepositScan- https://www.ars.usda.gov/midwest-area/wooster-oh/application-technology-research/docs/depositscan/), and determine the effective swath width by using a coefficient of variation of 25-35%. The effective spray width is the average of the three measurements, using a coefficient of variation (CV) ≤ 25%. If using a different method, please describe it in detail.

5.5.2 Ground Spray

Similar to that of the UAV, swath width is impacted by nozzle type and spray pressure (flow rate), position and orientation of the nozzles on the boom, release height, ground speed and environmental conditions. Use the same method used with the UAV to determine the effective spray width of the ground sprayer, at the predetermined boom height (tip of nozzle to ground or top of canopy), ground speed and nozzle set up, and placing water sensitive cards across the spray pass, avoiding placing cards on the tractor wheels track. Cards can be placed across the anticipated width, allowing for 50% extra on each side, for example, if the anticipated width of the swath is 4 m, place cards across 8 m (4 * 0.5 = 2 meters extra on each side). Cards can be spaced every 25 cm. Spray over the cards at the parameters above, allow for 20 m of spray before the tractor sprayer reaches the position of the cards and another 20 m of spraying after going over the cards. Repeat with clean cards at least three times during low wind conditions. Get coverage data on the individual cards (using scanner and software, *i.e.*, Snapguard, DepositScan- https://www.ars.usda.gov/midwest-area/wooster-oh/application-technology-research/docs/depositscan/), determine the effective swath width by using a coefficient of variation of 15-25%. The effective spray width is the average of the three measurements, using a CV) ≤ 20%. If using a different method, please describe in detail. Working width needs to be measured and recorded.

5.6 Calibration prior to trial

There are three major factors, that influence sprayer calibration:

a) Ground speed, *i.e.*, flight speed (km/h, mph)
b) Swath width (meters or feet)
c) Flow rate (L/min or g/min)

Calibrate following these steps:

1) Set vehicle up – move rotors, extend boom, etc.
2) Fill the tank to full capacity with clean water
3) Place the drone on a platform where the nozzle pattern can be visualized
4) With the rotors off, turn the pump on at desired flow rate setting (increase or decrease in voltage can change the pump output) and visually make sure that the nozzle sheet is fully established (no obstructions, partial clogging, etc.)
5) Confirm that each nozzle is providing the expected spray angle and orientation. When flat-fan broadcast nozzles are used, spray patterns from adjacent nozzles must overlap such that the resulting coverage is uniform across the effective spray swath at the used release height.
6) Using a graduated cylinder (or other suitable containers, pre-calibrated and marked) collect water output from each nozzle for 30-60 seconds while all nozzles are spraying. The output from each nozzle should be very similar and within no more than approximately 5% of each other, larger differences in output may indicate the nozzle is damaged or the pump is not accurate and either may need to be replaced. Depending on the position of the nozzle, it may also indicate uneven pressure. Large differences in output need to be fixed for uniform spray.

Nozzle flow rate can also be tested by ISO 5682 (Ref. 6.5, clause 6.5). Flow rates of nozzles are tested in a stationary condition by operating the pump.

7) Calculate total flow rate volume in liters/min or US gallons/min, which will be the sum of all the nozzles)
8) Calculate hectares per minute (HPM):
   a) HPM = flight speed (kph) X effective swath width (meters) / 600
   b) 1 m/s = 3.6 kph
9) Calculate the volume that will be delivered in liters per hectare using the formula below, an example is provided for clarity using values:
   a) Flow rate: 5 liters/minute
   b) Flight speed: 6 m/s
   c) Swath width: 6 meters
   d) HPM = (6 m/s * 3.6) X 6 / 600 = 0.216 hectares per minute
   e) Liters/ha = 5 liters/minute / 0.216 = 23.15 l/ha
   f) If the targeted volume in l/ha is not close to what is required for the application, changes to the flight speed, swath width or flow rate will have to be made.
10) Verifying deposition: make one pass with the drone at the desired flight pattern and all above settings (height, speed etc.) and verify coverage and deposition are uniform and will deliver the desired result. Using water sensitive paper is an optional step that will help visualize deposition and detect any other deficiencies. Repeat this step at least three times.

Outcome: Application rate, volume per area unit (US GPA or L/ha)
A pattern test is needed for verification and the coefficient of variation (CV) should be recorded

6. References

6.1 International Organization for Standardization (ISO). 2005. *Equipment for crop protection – Methods for field measurement of spray drift (ISO Standard No.22866: 2005).* Retrieved from https://www.iso.org/standard/35161.html.

6.2 American Society of Agricultural and Biological Engineers (ASABE). 2004. *Procedure for measuring drift deposits from ground, orchard, and aerial sprayers (ASABE standard S561.1)*. Retrieved from https://elibrary.asabe.org/abstract.asp?aid=44207&t=2.

6.3 Society of Environmental Toxicology and Chemistry Drift Risk Assessment Workshop (SETAC DRAW). Retrieved from https://www.spraydriftmitigation.info/setac-draw-workshop.

6.4 United States Environmental Protection Agency (EPA). 2016. *Generic Verification Protocol for Testing Pesticide Application Spray Drift Reduction Technologies for Row and Field Crops. Final Generic Verification Protocol for Pesticide Spray DRT.* Retrieved from https://www.epa.gov/sites/production/files/2016-06/documents/drt-protocol-06-21-2016-v2.pdf.

6.5 International Organization for Standardization (ISO). 2017. *Equipment for crop protection – Spraying Equipment – Part 1: Test methods for sprayer nozzles (ISO Standard No.5682-1: 2017).* Retrieved from https://www.iso.org/standard/60053.html.

6.6 American Society of Agricultural and Biological Engineers (ASABE). 2020. *Spray nozzle classification by droplet spectra (ASABE standard S572.3)*. Retrieved from https://elibrary.asabe.org/abstract.asp?aid=51101&t=2.