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Study design, methods, and data collection from UAV spray drift studies conducted in 2023 for the Unmanned Aerial Pesticide Application System Task Force (UAPASTF)

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Introduction

Study Team

- The Unmanned Aerial Pesticide Application System Task Force (UAPASTF) has contracted with the Stone Environmental field team to conduct ten UAV drift deposition field trials. Nine of these trails are GLP and one is non-GLP. Two of these trials are scheduled for September 2024.
- We partnered with local personnel whenever possible. This has included local farmers, CROs, spray drone experts, academic personnel, government authorities, and in-country industry folks.

Study Location

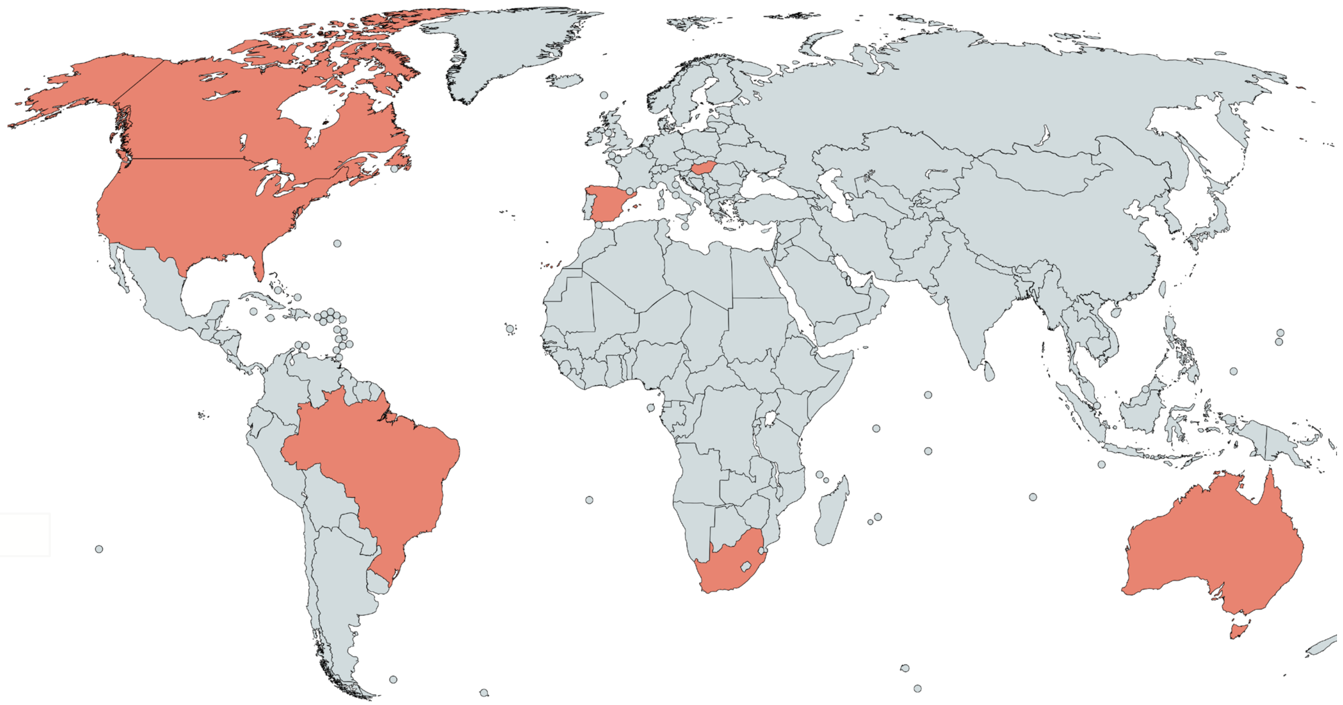
- Studies have been conducted in six (soon to be seven) countries around the world, and in four (soon to be five) regions (continents).

Study Timeframe

- The first non-GLP study was conducted February 2023.
- The first GLP study was conducted May 2023.
- The final and ninth GLP study will be conducted in September 2024.

Study Locations and Timeline

- Robstown, Texas, USA – February 2023 (Non-GLP)
- Katy, Texas, USA – April 2023 (Pattern Testing study only)
- Saint-Jean-sur-Richelieu, Quebec, Canada – May/June 2023
- Santa Helena de Goiás, Goiás, Brazil – August/September 2023
- Bugac, Bács-Kiskun, Hungary – October 2023
- Oropesa, Toledo, Spain – November 2023
- Robstown, Texas, USA – December 2023
- Castro, Paraná, Brazil – March 2024
- Clifton, Queensland, Australia – April 2024
- South Africa (2x – Delmas and Hertzogville) – September 2024 (upcoming)



Observational and Participatory Stakeholders Present

- Partners throughout the studies
  - Drone Spray Canada
  - DJI
  - Application Insight, LLC
- Texas, USA (non-GLP) – USDA, HSE-UAV
- Texas, USA (Pattern Testing) – Application Insights, LLC
- Canada – PMRA, Agriculture and Agri-food Canada
- Goiás, Brazil – São Paulo State University, AgIdea
- Hungary – Hungarian Ministry of Agriculture, Ministry of Agriculture and Rural Development of the Slovak Republic, Central Controlling and Testing Institute in Agriculture (CCTIA; Slovakia), National Forest Center (NFC; Slovakia), MyActionCam
- Spain – Spanish Ministry of Health, ACRE Solutions
- Texas, USA – USDA
- Paraná, Brazil – Federal University of Santa Maria
- Australia – APVMA, University of Queensland
- South Africa (2x) – September 2024 (upcoming)

Study Design

Study design followed the UAPASTF guidance protocol.

Verification and Calibration

- Sprayer speed verification
- Nozzle verification and pressure verification

Pattern Testing

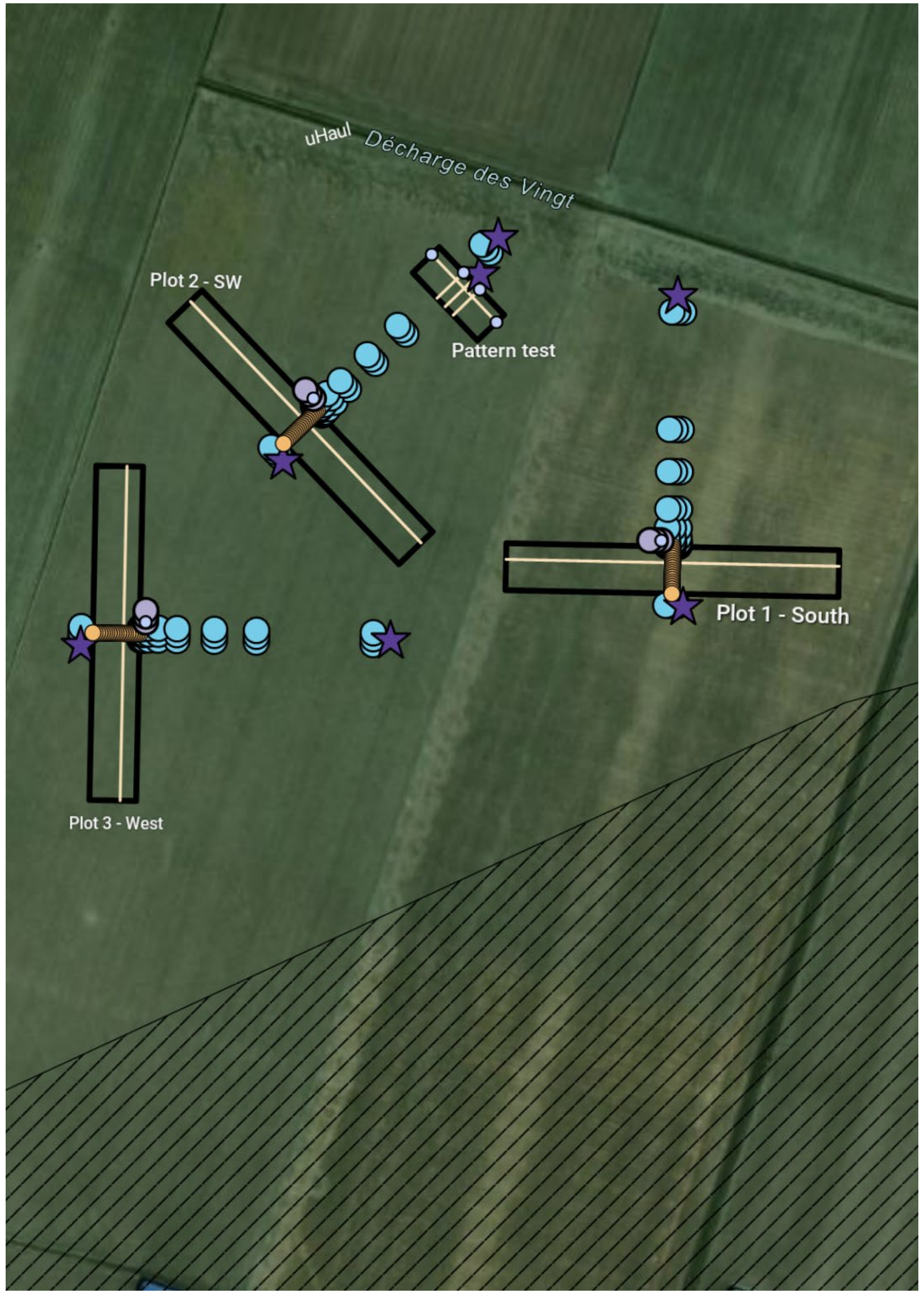
- Three replicates per nozzle for a total of nine passes.
- Determination of swath width and displacement for Event Applications.

Event Applications

- Three replicates of each nozzle droplet classification pairing (XR110015/XR11003, TT11001/TT11003, AIXR110015/AIXR11003).
- Nine UAV and nine reference ground applications in total.

Quality Control Samples

- Photostability samples
- Transit stability samples
- Tank mix samples
- Source water characterization samples



UAV – T30

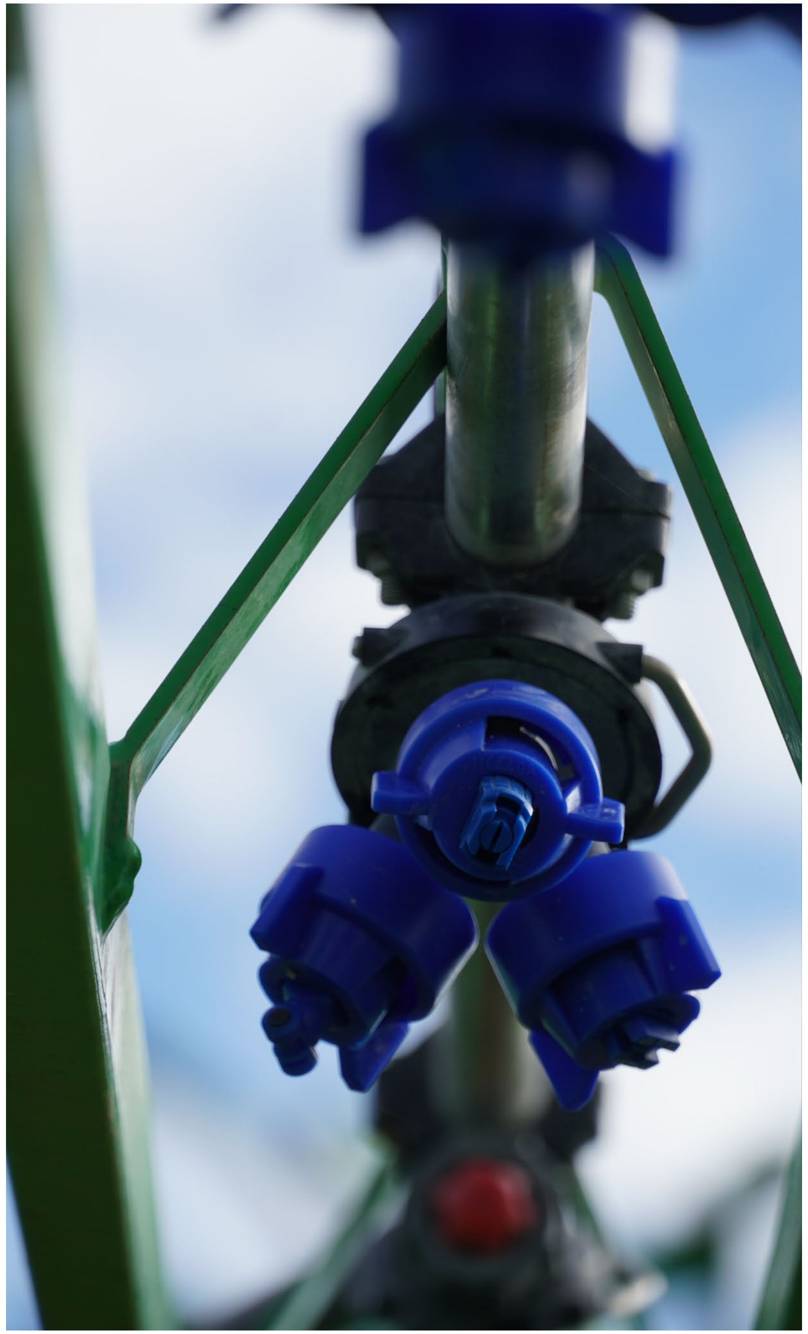
The DJI T30 was used for all studies to achieve a consistent benchmark/ comparator.

- The T30 uses traditional hydraulic nozzles. This allows comparisons to similar nozzles on a reference ground sprayer.
- UAV technology is moving fast, and we wanted to have a consistent dataset across all studies. The T30 was chosen as this benchmark.
- At the time of study initiation, the T30 had significant global market share, and was in the mid-range of existing and anticipated UAVs in terms of weight and payload capacity.

Nozzles

Three nozzles were used to achieve a fine, medium and coarse droplet spectrum.

- For the UAV XR110015, TT11001*, and AIXR110015 nozzles were used at a target pressures of 30, 40, and 30 psi, respectively.
- For the reference ground sprayer XR11003, TT11003, and AIXR11003 nozzles were used at a target pressure of 40 psi.
- The XR nozzles were targeting a fine droplet, the TT nozzles were targeting a medium droplet, and the AIXR nozzles were targeting a coarse droplet

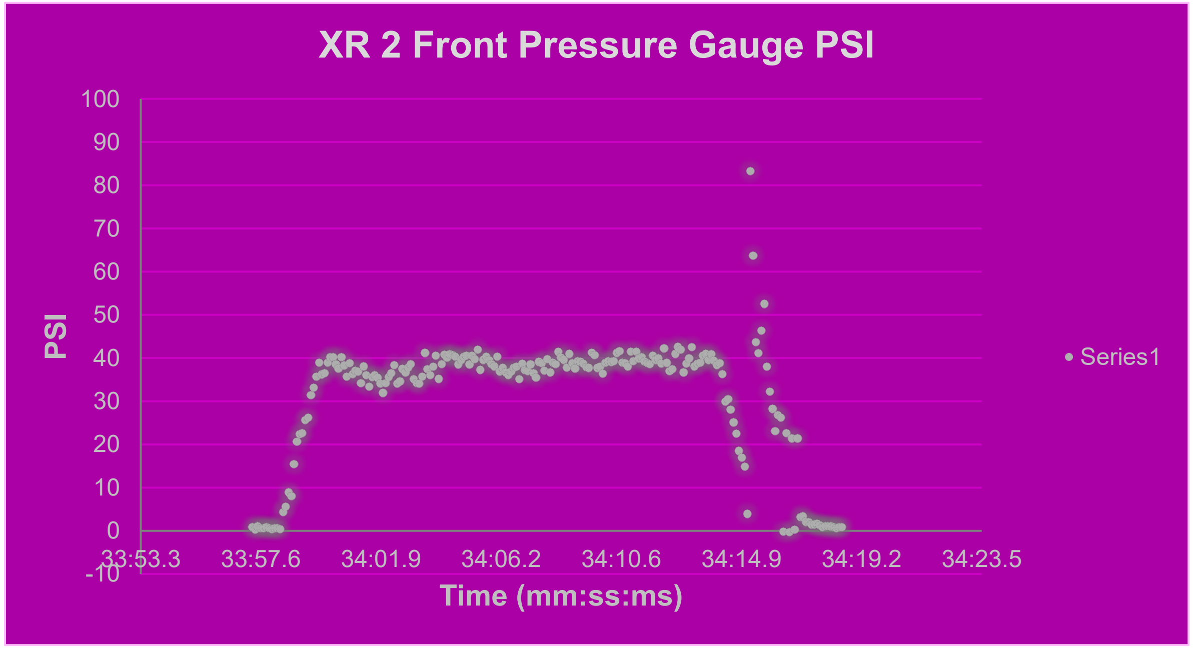


*In the Texas non-GLP study, the Texas pattern test study, and in the Canada study TT110015 nozzles were used.

UAV pressure monitoring

UAV pressure was monitored during nozzle verification, pattern testing, and multi-swath applications

- T30 application rate is controlled by the internal computer which controls two pumps via flow rate controllers.
- To verify the pressure, we installed two inline pressure loggers recording at 0.1 second intervals.



Calibration and Verification

The nozzle flow rate was verified for the UAV and ground sprayer

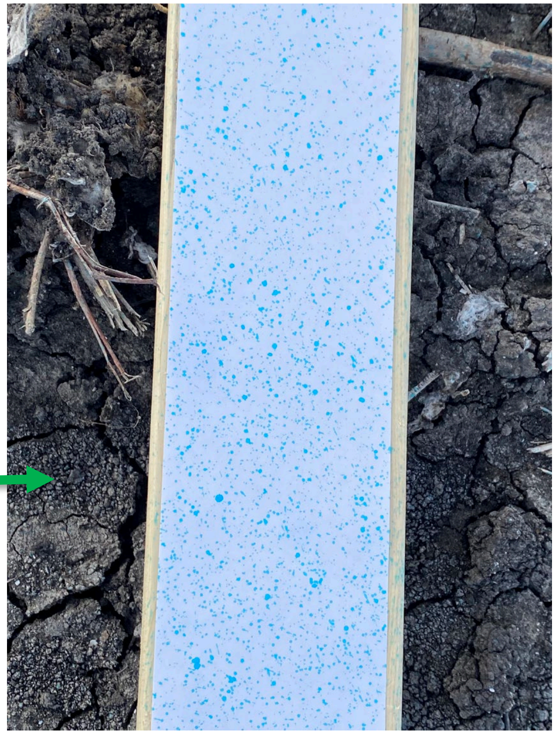
- Verification was performed using SpotOn® SC-1 calibrators.
- Pressure was verified with inline Track-It™ pressure loggers.
- Inconsistencies were addressed by swapping out defective nozzles, documenting the actual versus target pressure, adjusting the sprayer speed, and/or contacting the nozzle manufacturer.

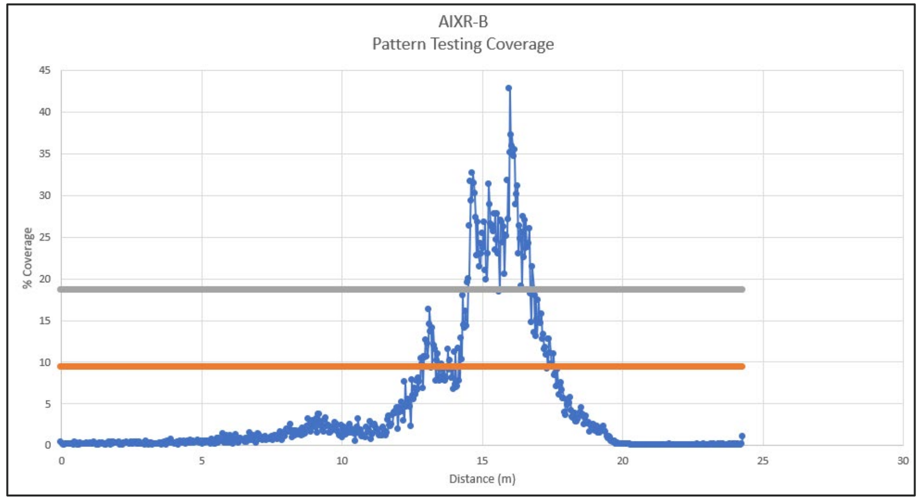
Pattern Testing

UAV spray pattern was measured for the UAV, release height, nozzle, forward speed, and environmental conditions

- Tests were performed in a crosswind. This has not been the industry standard, since results are more variable. However, we saw the need to perform pattern testing in the same environmental conditions as we would be testing in.
- Three passes were performed for each nozzle.
- Deposition of FD&C blue dye was collected on receipt paper and run through the Swath Gobbler™.
- Swath width and swath displacement were calculated based on average percent coverage.

Pattern Testing





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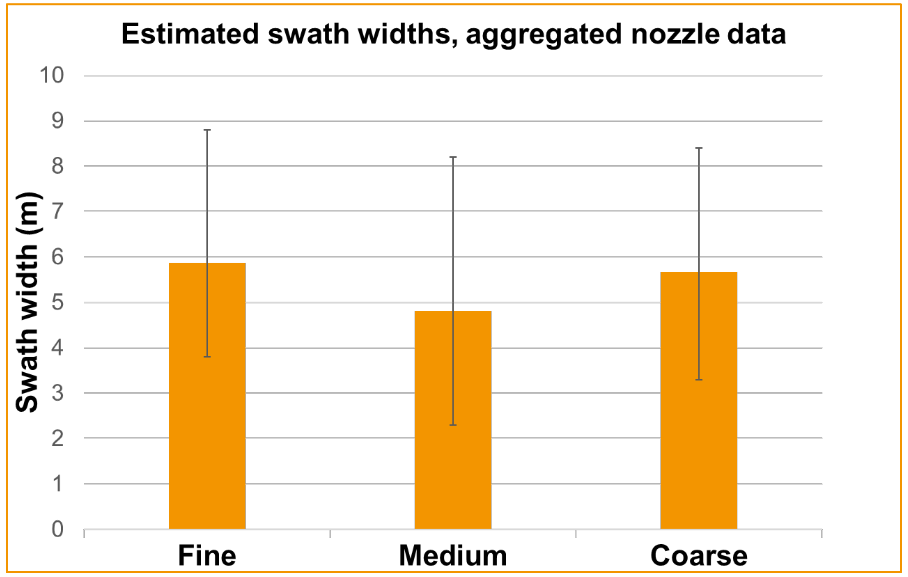
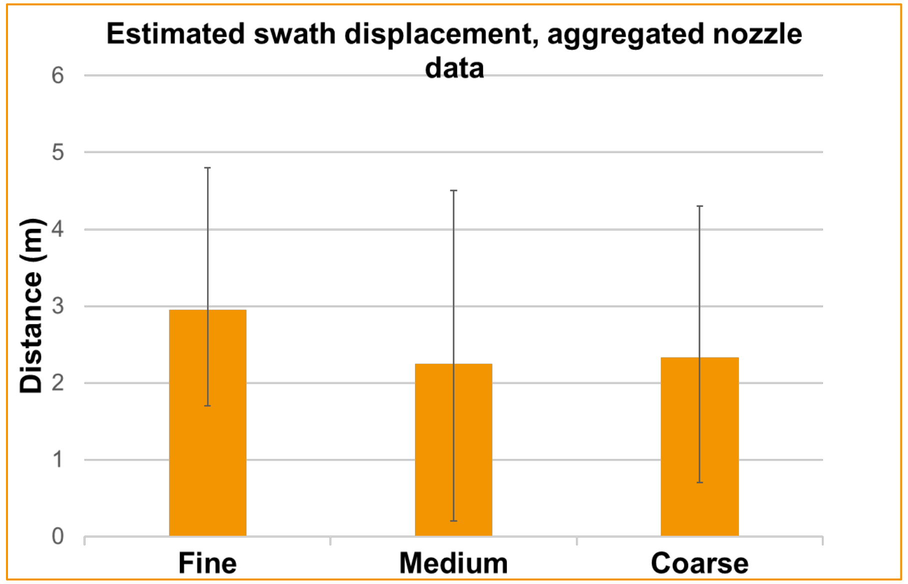
Pattern Testing Analysis

Swath width was determined as width of swath at ½ of average percent coverage

- There was add variability with crosswind methodology.
- An iterative process using an excel worksheet was used to determine the swath width.
- Swath displacement was calculated by determining the difference between the flight path center line and the calculated swath center line.





Tank Mixing

PTSA (1,3,6,8-pyrene tetrasulfonic acid tetrasodium salt) and FD&C Blue #1 were added to the tank mix.

- An "elixir" of 25% w/v powdered dye in distilled water was created for both the visual blue dye and the fluorescent PTSA dye.
- The blue elixir and PTSA elixir were added to the tank mix at a concentration of of 4.00 ml/L.
- The resulting tank mix had a concentration of 1 g/L for both the blue and PTSA dyes.

Tank Mix Transfer and Samples

Ground sprayer was used as a nurse tank.

- For the UAV applications the tank mix was transferred from the ground sprayer tank into the UAV prior to each application.
- For some studies, a new tank mix was made each day. For other studies, the tank mix was stored overnight.
- Tank mix samples were collected before the first application and after that last application each day.
  - In later studies an additional midday tank mix sample was collected.
- Tank mix samples were preserved with 50% isopropyl alcohol* as soon as was possible.

*For some studies isopropyl alcohol was not readily available and ethanol or a similar preservative was used.

Event Application

Application Parameters

- The target application rate was 15 GPA (140 LPH) for the ground applications and 3.5 GPA (32.7 LPH) for the UAV applications.
- The target sprayer speed for each study was based on sprayer verification results and equipment constraints.
- The target pressure was 50 PSI for the ground sprayer and 30 or 40 psi for the UAV depending on the nozzle.

Pair Events

- UAV and ground applications were paired for like nozzles producing the same droplet spectrum (XR110015/XR11003 – fine, TT11001/TT11003 - medium, AIXR110015/AIXR11003 - coarse).
- There were nine sets of paired applications for a total of eighteen applications.
- Paired events were performed as close in time to each other as was possible given constraints with sample collection and wind conditions.

Passes

- The length of the application area was 285 m (935 ft)
- The width of the application area was targeted to be similar for the ground and UAV events.
- This meant the UAV applications had between two and four passes, and the reference ground applications had either one or two passes based on the boom width.

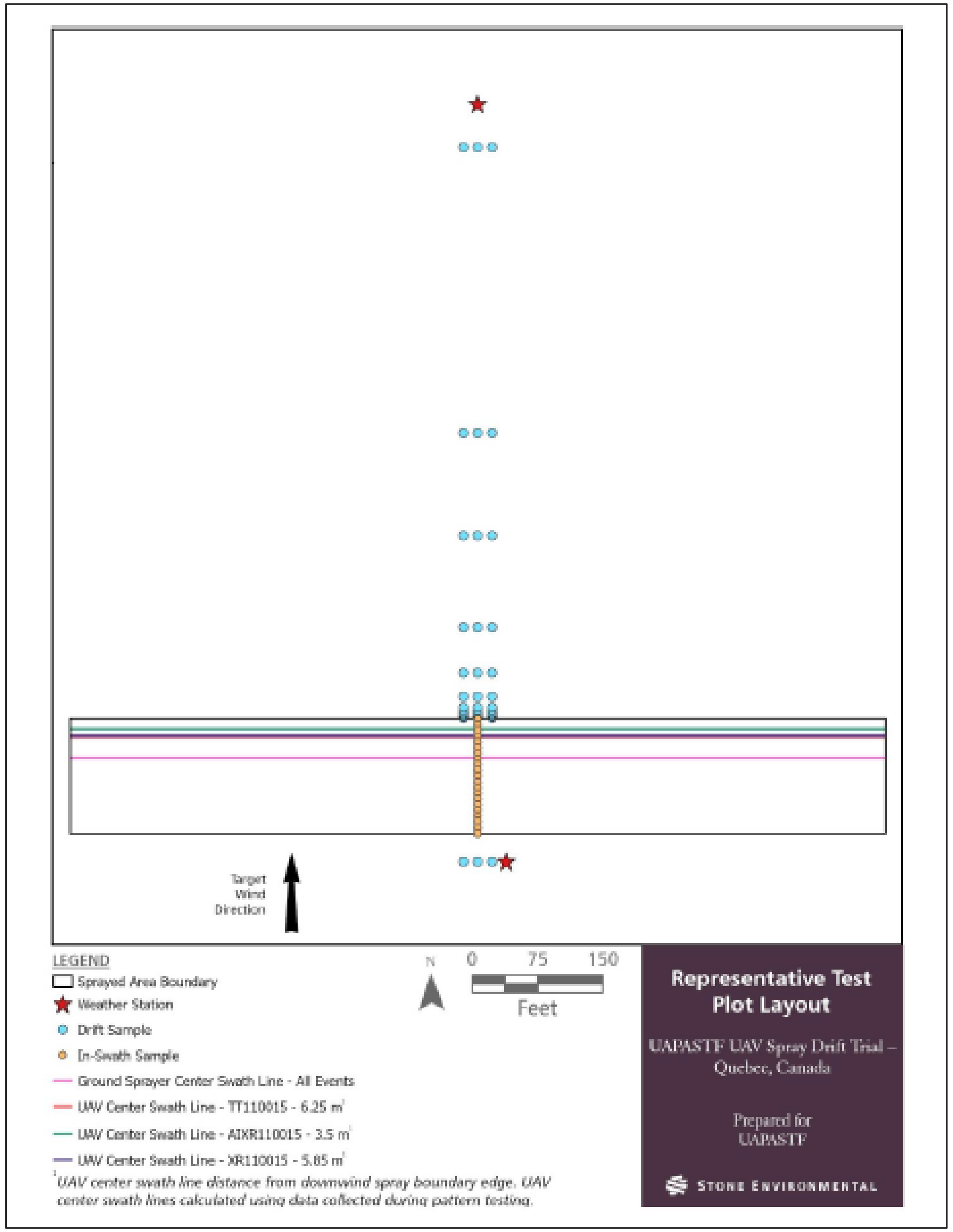
Event Application Samples

Horizontal Drift Deposition Samples

- Grafix® Clear DuraLar™ (BoPET: bi-axially oriented polyester film). 4”x4” cards with a thickness of .010” or .020” (depending on the study).
- Three upwind control samples.
- Application verification samples at 2 m spacing.
- Three downwind transects at 12 distances from the edge of spray of: 0.5, 1, 1.5, 2, 3, 4, 8, 16, 32, 64, 100, and 200 m.

Vertical Deposition Samples

- Monofilament nylon string
- Three downwind sample locations for each UAV application located 5 m downwind of edge of field.
- Five vertically defined samples per location at: 0-1, 1-2, 2-3, 3-4, and 4-5 m above ground.



Event Application Samples

Sample Collection

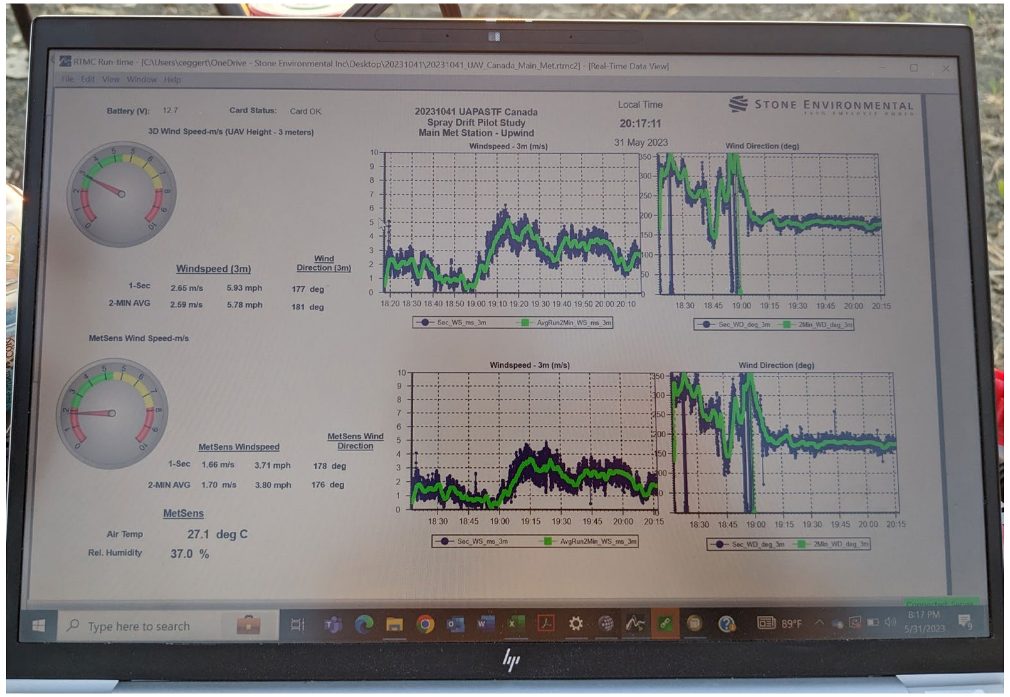
Samples

- Sample collection began 5 minutes after application to allow adequate time for deposition in the downwind collection area.
- Sample collection was performed by trained staff from downwind to upwind to prevent any cross contamination.
- One person collected samples along each drift line.
- Sample stands were wiped with alcohol wipes between each application.
- After sample collection, samples were placed in dark storage until arrival and analysis at the fluorometry lab.

Meteorological Stations

Two weather stations were deployed.

- An upwind weather station measured 3-D wind speed and direction at the UAV boom release height (3 m), 2-D wind speed and direction at ground boom release height (20 inches), temperature, relative humidity, barometric pressure, and solar radiation.
- A downwind weather station measured 2-D wind speed at 3 m and at 20 in, and temperature, relative humidity, and barometric pressure.
- During applications, the meteorological conditions were monitored from a laptop to ensure the wind speed and direction were with in range.



Meteorological Stations

Application ranges

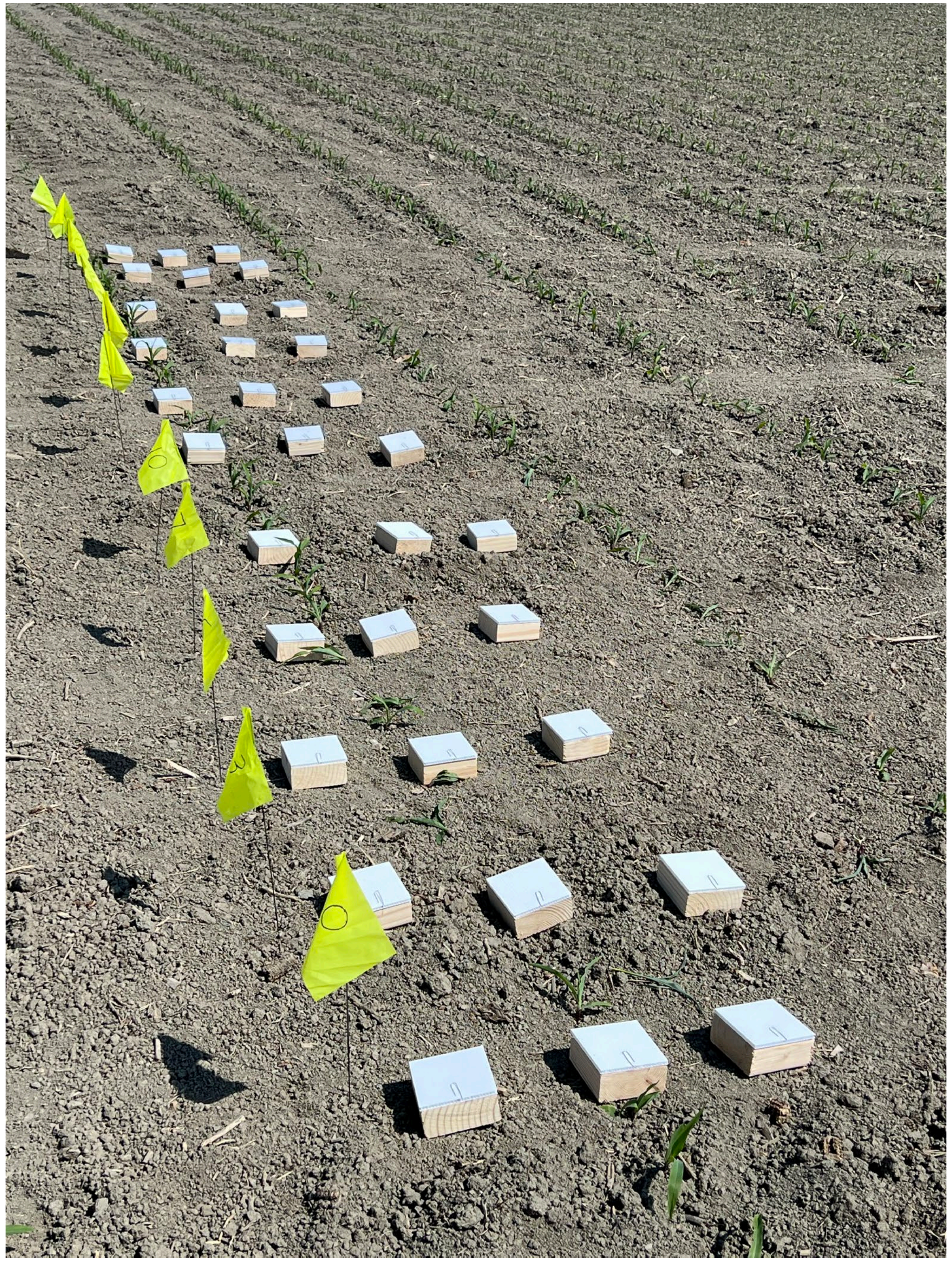
- The target wind speed during applications was 2.0 – 5.0 m/s (4.5 – 11.2 mph) at boom height.
- The target wind direction was within 30° of the field orientation.

Parameter	Height Above Ground on Upwind Met Station	Height Above Ground on Downwind Met Station
3D Wind Speed and Direction	3 m	NA
2D Wind Speed and Direction	51 cm	51 cm, 3 m
Temperature	51 cm	51 cm, 3 m
Relative Humidity	51 cm	51 cm, 3 m
Barometric Pressure	51 cm	51 cm, 3 m

Photostability Samples

A photostability test was conducted to ensure PTSA did not degrade in the sunlight during the time-course of an application and sample collection time.

- PTSA was chosen because it is a stable, safe, and relatively inexpensive dye with a low detection limit.
- However, PTSA has been shown to degrade in UV light.
- To ensure this degradation is minimal over the timeframe of sample collection a photostability test was conducted.
- 11 sample durations were selected with three replicates each.
- 33 mylar cards were spiked with 10 µl of 1.0 g/L PTSA solution and deployed on sample stands during the middle of the day.
- Samples were collected 0, 3, 5, 7, 10, 15, 30, 45, 60, 75, and 90 minutes after they were deployed.
- Solar irradiance was measured during the duration of the photostability test.



Transit Stability Samples

Transit stability samples were generated for each study.

- The transit stability samples were transported with all the other samples to ensure sample stability during transport.
- Samples were generated at low and high concentrations. Low samples were spiked with 10 µl of 0.1 g/l solution which was approximately 10x the LOD High samples were spiked with 10 µl of 1.0 g/l solution which was approximately 100x LOD. Blank samples were also generated.
- Three replicates at each concentration were generated for each sample media type (DuraLar and string).

Dust Blank Events

For some studies dust blank “applications” were performed.

- If a field was generating dust during applications a dust blank “application” may have been performed.
- The UAV was flown with a full payload but with the spray system turned off.
- A subset of upwind, AV and downwind samples were collected in the same manner as standard applications.
- These samples were analyzed to see if the dust had any effect on fluorescence of the samples.

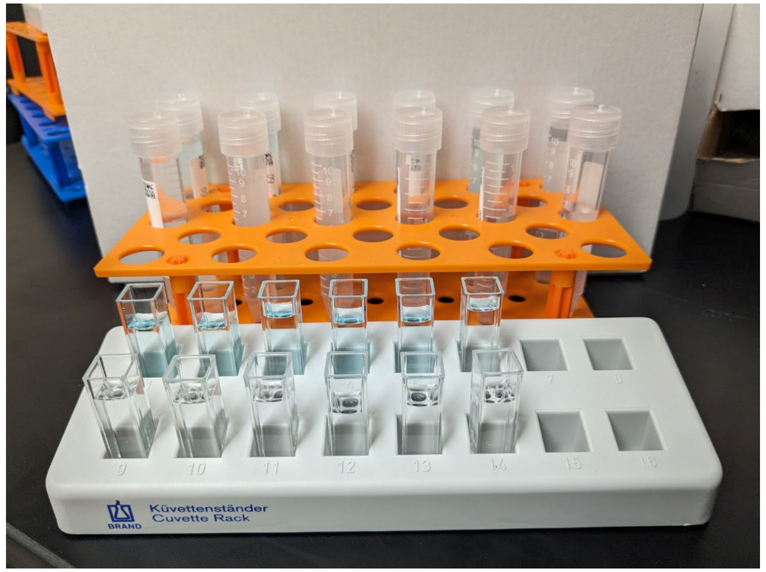
Lab Analysis

Sample analysis occurred at the Stone fluorometry lab in Montpelier, Vermont.

- Samples were brought back to the lab by Stone staff.
- The preserved tank mix samples were used to generate calibration curves.
- DuraLar™ and string samples were analyzed according to application and were matched to the corresponding tank mix sample calibration curve.
- Each sample was washed with a minimum of 10 ml of 10% isopropyl alcohol in water solution. If the sample concentration was higher the rinse volume was greater than 10 ml.
- The rinse solution was poured into single-use 4.5 ml methacrylate cuvettes and 10 ml vials for storage.

Storage stability study

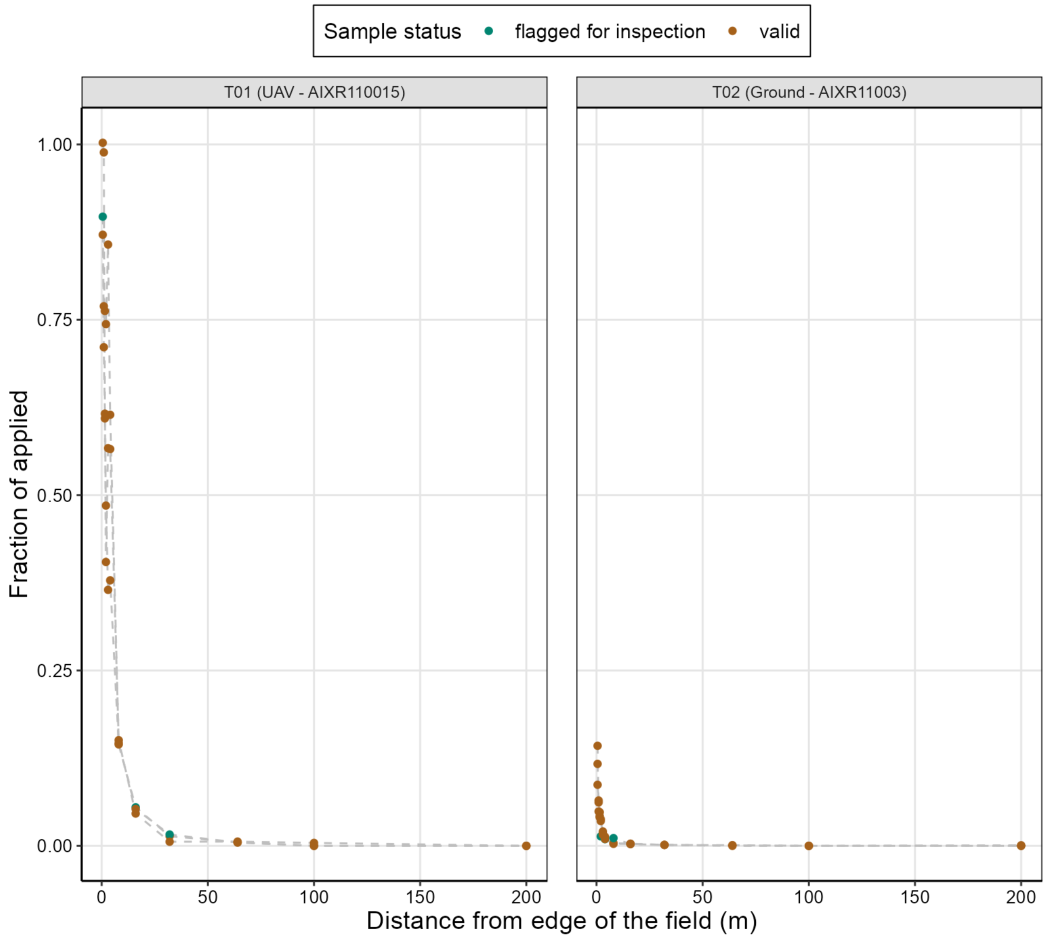
- We are conducting a storage stability study for the unwashed DuraLar™ and string samples.



Data Analysis

After fluorometry analysis was complete, fraction of applied values were calculated for each sample.

- Fraction of applied values were calculated based on the tank mix calibration curve and rinse volume for the given sample.
- Fraction of applied values were used to generate deposition curves.
- Curves can be compared across nozzle types, droplet size and environmental conditions including wind speed, temperature and relative humidity.
- Curves can also be compared to regulatory drift curves.



Dataset Generated

Nine GLP studies on five continents

- Replicating the same study nine times has created a large dataset of nearly 10,000 GLP horizontal deposition samples.
- We've engaged stakeholders including regulator agencies in important growing regions worldwide.
- Proof of concept for the UAPASTF guidance protocol.

Methodology refinements

- For pattern testing we moved from Kromekote cards processed with image processing software to receipt paper and the Swath Gobbler. This was faster, more precise and more cost effective.
- For the application verification samples we switched from using petri dishes to DuraLar™ cards with no issues of splashing.
- We identified an issue with the AIXR 110015 nozzle through our verification process and worked with TeeJet to rectify this issue.

Additional Questions to Investigate

The goal of the UAPASTF and these studies is to generate regulatory information and data.

These studies have also created a solid baseline from which further research could be done.

- Rotary atomizers vs. hydraulic nozzles.
- Comparisons to other makes and models of UAV.
- Comparisons of sample media for vertical and horizontal drift.
- Comparison of UAV spray and traditional aerial spray.

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Thank you.

Contact / arice@stone-env.com

Note: All data generated by this study protocol is proprietary to the UAPASTF and its member companies.