



## A study on droplet deposition of nano DAP using unmanned aerial hybrid sprayer on peanut (*Arachis hypogaea*) crop

RAJESH P<sup>1</sup>, A P MOHANKUMAR<sup>1\*</sup>, R KAVITHA<sup>1</sup>, B SUTHAKAR<sup>1</sup>, A SURRENDRAKUMAR<sup>1</sup>  
and K GANESAN<sup>1</sup>

Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641 003, India

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### ABSTRACT

The experiment was conducted during rainy (*kharif*) seasons of 2023 and 2024 at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu to study the application of nano DAP using a hybrid drone in groundnut (*Arachis hypogaea* L.) crops. The UAV, model DH-AG-H1, equipped with a 12 L sprayer tank and a 16,000 mAh battery. The UAV's performance was assessed across multiple parameters, including spray droplet deposition rate, droplet size distribution, density, area coverage, uniformity and drift characteristics. The UAV operated at a spray height of 1 m and a forward speed of 3 m/s, achieved an operational efficiency of 4.11 ha/h. Results showed that in *kharif* 2023 season, droplet densities ranging from 35–76 drops/cm<sup>2</sup> in the target zone, with minimal horizontal drift (0–22 drops/cm<sup>2</sup>) and very low vertical drift (0–6 drops/cm<sup>2</sup>). The *kharif* 2024 season data indicated droplet densities from 31–70 drops/cm<sup>2</sup> in the target zone, with horizontal drift ranging from 0–20 drops/cm<sup>2</sup> and vertical drift from 0–14 drops/cm<sup>2</sup>. The hybrid drone demonstrated VMD/NMD ratios from 1.02–1.66 and droplet densities between 31 and 76 drops/cm<sup>2</sup>, indicating effective coverage with a diverse range of droplet sizes, from very fine to ultra-coarse. These results confirmed the UAV's precision in reducing fertilizer use, soil compaction and chemical drift, highlighting its efficiency in promoting sustainable agriculture.

**Keywords:** Groundnut crop, Nano DAP application, Spray drift analysis, Spray droplet deposition, UAV spraying technology

Groundnut (*Arachis hypogaea* L.) is a vital crop in India, covering 4–5 million hectares and producing 6–7 million metric tonnes annually, primarily in Gujarat, Andhra Pradesh and Tamil Nadu (Lakshmi *et al.* 2019). Conventional spraying methods result in excessive chemical use, reduced spray uniformity, and inadequate deposition and coverage, which increase pesticide costs and contribute to environmental pollution (Radoglou-Grammatikis *et al.* 2020). Drones effectively controlled weeds and increased greengram yield using pendimethalin 0.75 kg/ha and 60 L/ha spray fluid, reducing herbicide dose, spray fluid and labour compared to manual spraying (Ramesh *et al.* 2024). UAV sprayers, whether battery-operated offer a more efficient and safer alternative. The application of nano-fertilizers alongside 75% of the recommended N significantly enhanced maize yields and productivity while reducing N fertilization by 25% (Rawat *et al.* 2024). Nitrogen management through inorganic fertilizers and nano-urea foliar spray significantly improved garlic yield, quality and storage attributes, making it suitable for semi-arid conditions (Choudhary *et al.* 2024). The intercropping of ginger with groundnut recorded the

highest benefit-cost ratio (3.42), highlighting its economic viability for hill farmers in the eastern (Rymbai *et al.* 2021). The importance of optimizing nozzle configurations and flight height to achieve uniform droplet distribution and effective pesticide application, with significant impacts from UAV rotor speed and environmental factors on spray effectiveness (Dengeru *et al.* 2022).

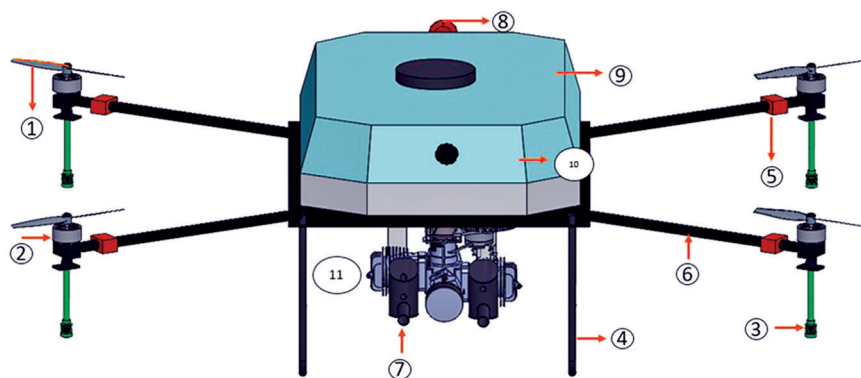
The novelty of this study lies in enhancing spray deposition density using nano DAP (diammonium phosphate) and demonstrating the advantages of a hybrid UAV sprayer. The hybrid drone reduces fertilizer use through precision application, minimizes soil compaction, and lowers chemical drift, providing superior environmental safety compared to traditional sprayers.

This investigation focuses on examining spray drift characteristics, including droplet deposition rate and size, in groundnut crops using a hybrid UAV sprayer, offering technical guidance for safe and effective aerial spraying.

### MATERIALS AND METHODS

The DH-AG-H1 (Dhaksha Agrigator Hybrid) hybrid drone system is designed for agricultural applications, featuring a 12 L sprayer tank for precise and efficient crop spraying. It operates with a combination of an internal

<sup>1</sup>Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. \*Corresponding author email: [apmohankumar@tnau.ac.in](mailto:apmohankumar@tnau.ac.in)



1. Foldable Propeller, 2. BLDC Motor, 3. Flat fan nozzle, 4. Landing gear, 5. ESC, 6. Foldable arm, 7. Exhaust pipe, 8. GPS, 9. Payload tank, 10. Petrol tank, 11. Engine

Fig. 1 DH-AG-H1 sprayer.

combustion two-stroke engine and a BLDC (brushless direct current) motor, providing a total power output of 6000 W.

This hybrid drone measures 2272 × 2388 × 643 mm and has a maximum weight of 47.6 kg (Fig. 1). The engine power is generated by the generator, which is connected to the receiver and controlled via remote control. The power is then distributed through the PDB (power distribution board) to the flight controller, which regulates the ESCs (electronic speed controllers) that manage the motors. The system is equipped with GNSS (global navigation satellite system) for navigation and includes autonomous flight features such as geo-fencing and an autonomous flight termination system for enhanced operation.

*Experiment plot:* The experiment was conducted on a peanut crop during *kharif* season (July to October 2023 and June to September 2024). The peanut crop, spaced at 30 cm × 10 cm, was cultivated in an 85 m × 10 m plot, reaching a height of 15 cm @60 days of growth. In this study, nano-diammonium phosphate (nano-DAP) was applied using a hybrid UAV to enhance nutrient absorption efficiency and increase crop yield (Singh *et al.* 2021). Table 1 provides the specifications of the hybrid drone used.

*Assessment of spray deposition:* The collectors used 50 mm × 50 mm water-sensitive paper (WSP) to visualize spray deposition patterns during UAV application. The paper, coated with a dye that reacts to liquid, highlights spray droplet distribution. WSP was mounted on flat iron plates and positioned along the UAV's flight path, extending up to 9 m (Chen *et al.* 2020). As per ISO/DIS 23117-2 guidelines, collectors, at least 5 cm × 5 cm, were spaced at 1 m intervals (Shan *et al.* 2024). The WSPs were numbered sequentially from left to right following the UAV's flight for data analysis. After spraying, they were collected to assess spray drift patterns. UAV calibration is followed by the ASAE S386.2 FEB1988 (R2013) standard.

*Drift sampling methodology:* An on-site experiment was conducted to examine spray drift and droplet movement outside the target zone. For horizontal drift, WSPs were placed at positions D<sub>1</sub>, D<sub>2</sub>, D<sub>3</sub> and D<sub>4</sub>, spaced 2 m apart from the target zone (Luo *et al.* 2018). For vertical drift, samples were placed 4 m from the target zone at vertical

distances of 0.5 m (V<sub>1</sub>), 1 m (V<sub>2</sub>), 1.5 m (V<sub>3</sub>) and 2 m (V<sub>4</sub>) from the ground (Wang *et al.* 2018).

*Configuration of UAV spray parameters:* Flat fan nozzles were chosen for the application of nano-DAP using the battery-operated UAV in the experiment (Hensley *et al.* 2008). Each nozzle had a flow rate of 0.5 L/min, following the standard operating procedures (SOPs). Weather conditions like air velocity, orientation and temperature affect UAV spray patterns and cause drift, risking uneven application and environmental impact. The pilot controlled and monitored

the UAV's field operations using the Aerogcs green mobile app. The operational settings included a forward speed of 3 m/s, a spray height of 1 m above the crop canopy and 1.1 m above the ground, and a swath width of 4 m (Rajesh *et al.* 2024). The overall discharge rate was set to 2 L/min.

*Environmental data collection:* The experiments, conducted in the morning recorded environmental conditions

Table 1 DH-AG-H1 hybrid drone specifications

Particulars	Values
Type	Quadcopter
Model	DH-AG-H1
Propulsion type	Hybrid (Electric and IC)
Extended airframe size, (L × W × H) (mm)	2272 × 2388 × 643
Folded dimensions, (L × W × H) (mm)	950 × 850 × 570
Propulsion system	IC engine with BLDC motor, 6000 watts output
Payload capacity (L), Fuel tank capacity (L)	12, 3.5
Engine (rpm)	10000
Unladen weight (kg)	34.3
Take-off weight (kg)	47.6
Flight altitude (m)	1–15
Forward travel speed (m/s)	0–5
Type of spray nozzle	Flat fan nozzle
Number of nozzles	4
Discharge rate per nozzle (L/m)	0.42–0.50
Spray discharge rate (L/m)	1.68–2.0
Spray width (m)	2–4
Remote controller communication distance (km)	0.5
Endurance (min)	35
Propeller diameter (mm), Pitch (mm), Motor (rpm)	1016, 332.16, 3836–4000

with temperatures ranging from 24.6–26.4°C, wind speeds of 1.4–3.1 m/s from the SSW (202.5°–225°), and wind direction measured between 202.5° and 270.0° (south-southwest to west-southwest), using an IoT system based on the ESP8266 platform with wind direction sensor (RS-485 JXTC).

*Assessment of droplet distribution:* Water-sensitive paper (WSP) is utilized to visualize spray deposition patterns and quantify droplet density and distribution. Droplet size distribution and density were assessed using instruments such as the micro droplet analyzer and macro droplet analyzer. Following each spray test, Each WSP was separately collected, labelled in sequence, and placed in specific envelopes for transport to the lab for further analysis. The process adhered to standards, including ISO 22866 for spray drift analysis and ASAE S386.2 FEB1988 (R2013) for UAV calibration.

*Micro-droplet and macro-droplet analyzers:* Water-sensitive papers (WSPs) were analyzed using micro-droplet and macro-droplet analyzers (LABLINE-DMS 101, India) to measure deposition density (droplets/cm<sup>2</sup>) and uniformity (%) in the spray distribution area. In the lab, these analyzers determined droplet size and distribution, with key metrics including Dv0.1, Dv0.5 (volume median diameter, VMD) and Dv0.9, all measured in micrometers (µm). Dv0.1 corresponds to the droplet size containing 10% of the total spray volume. Dv0.5 (VMD) defines the size where 50% of the volume consists of smaller droplets, and

Dv0.9 indicates the droplet size below which 90% of the spray volume is found (Liao *et al.* 2019). These metrics are crucial for assessing the effectiveness and coverage of the spray application.

The process for analyzing droplet sizes consisted of several steps are at first microscopic and macroscopic images of the spray droplet samples were taken. The captured images were converted to grayscale, with adjustments made to contrast and threshold levels. Output results were calculated, including volume median diameter (VMD), number median diameter (NMD), droplet density and the percentage of volume coverage (Dengeru *et al.* 2022).

## RESULTS AND DISCUSSION

*Characterization of spray droplet distribution and deposition:* The droplet deposition and droplet size for each sample at every sampling location were analyzed using the micro and macro-droplet analyzers (Richardson *et al.* 2020). The results, demonstrate detailed analysis of droplet deposition profiles across each layer at specified locations, (Table 2) (Fig. 2).

*VMD/NMD ratio:* The VMD/NMD ratio is an important parameter for assessing the uniformity of spray droplet sizes. A ratio closer to 1 indicates more uniform droplet sizes. In the *kharif* (2023) season, the VMD/NMD ratio ranged from 1.07–1.61, with VMD values between 341 µm and 793 µm, and NMD values from 289–494 µm, showing

Table 2 Detailed analysis of droplet deposition profiles across each layer at specified locations

Height 1 m, Speed 3 m/s								
No. of samples	Location of WSP	VMD (µm)	NMD (µm)	VMD/NMD	Droplet density (drops/cm <sup>2</sup> )	DV <sub>0.1</sub>	DV <sub>0.9</sub>	Droplet size as per VMD classification
<i>Kharif</i> (2023)	1	341	289	1.18	56	135	577	Medium
	2	374	310	1.21	65	160	626	Coarse
	3	793	494	1.61	69	301	721	Ultra-Coarse
	4	432	392	1.10	47	225	673	Very Coarse
	5	451	304	1.48	76	164	554	Very Coarse
	6	491	457	1.07	54	247	808	Very Coarse
	7	563	392	1.44	66	240	717	Extremely Coarse
	8	516	444	1.16	53	231	836	Very Coarse
	9	471	365	1.29	35	228	681	Coarse
<i>Kharif</i> (2024)	1	452	422	1.07	40	170	801	Very Coarse
	2	407	297	1.37	44	187	558	Very Coarse
	3	505	308	1.64	56	233	678	Extremely Coarse
	4	654	501	1.31	51	245	803	Extremely Coarse
	5	411	337	1.22	70	163	617	Very Coarse
	6	383	292	1.31	57	150	546	Coarse
	7	431	259	1.66	63	169	603	Very Coarse
	8	363	271	1.34	45	162	543	Coarse
	9	60	59	1.02	31	23	101	Very Fine

WSP, Water sensitive paper; VMD, Volume median diameter; NMD, Number median diameter.

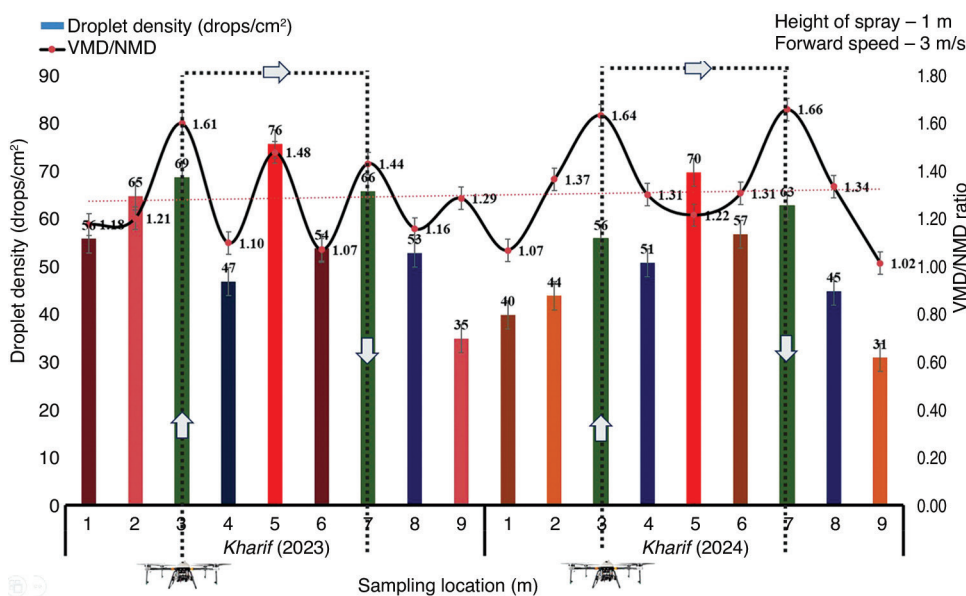


Fig. 2 Variability in droplet density and VMD/NMD ratio at different sampling locations for UAV spray application  
 VMD, Volume median diameter; NMD, Number median diameter.

moderate variation in droplet (Lv *et al.* 2019). In the *kharif* (2024) season, the VMD ranged from 60–654  $\mu\text{m}$ , and NMD from 59–501  $\mu\text{m}$ , resulting in ratios from 1.02–1.66, indicating more variability. The ratio varied from 1.09–1.66 in *kharif* (2023) season, reflecting a wide range of droplet sizes from fine to coarse. The *kharif* (2024) season showed ratios from 1.02–1.66, suggesting a broad range of droplet sizes. These results demonstrated the ability to achieve a wide range of droplet sizes, which can be advantageous for various spraying applications, improving coverage and overall effectiveness.

**Droplet density:** Droplet density, measured in drops per square centimeter, varied across the datasets, indicating differences in deposition rates. In the *kharif* (2023) season, densities ranged from 35–76 drops/cm<sup>2</sup>, while in the *kharif* (2024) season, densities ranged from 31–70 drops/cm<sup>2</sup> (Wang *et al.* 2020). The highest densities were consistently observed at location 5 across all datasets, suggesting an overlap in the spray path, potentially leading to over-application.

**Spray distribution pattern:** The spray distribution pattern was assessed based on the spread of droplet deposition across different WSP locations. The observed pattern indicates that locations 3 and 7, situated along the central path of the drone's spray, received higher deposition rates due to direct nozzle coverage. This pattern was consistent across all datasets, highlighting the need for precise control over the drone's flight path to ensure even distribution. The 4 m spray width produced uniform coverage and effectiveness.

**Characterizing droplet size variation:** The characterization of droplet size is essential for understanding drift and deposition. Across *kharif* season (2023 and 2024), droplet sizes ranged from fine to ultra-coarse, showing a wide range of VMD values. This variation demonstrates

the system's ability to produce diverse droplet sizes, suitable for different applications (Lv *et al.* 2019, Chen *et al.* 2020, Wang *et al.* 2020).

**Deposition pattern:** Deposition analysis measures the amount of material deposited on the target area. The data indicate that locations 3 and 7 had higher deposition rates due to direct coverage by the spray path. The highest deposition was consistently at location 5, showing the system's efficiency in thoroughly covering critical areas. This pattern suggested the need for careful adjustment to ensure even and efficient application.

*Environmental impact of battery-operated UAV*

**sprayers:** Nano DAP, when applied through UAV sprayers, provides targeted and efficient nutrient delivery to crop zones. This method boosts nutrient absorption efficiency and reduces waste associated with traditional broadcast techniques (Paul *et al.* 2023). Utilizing such nano-fertilizers enables farmers to improve crop yields and minimize environmental impacts by lowering runoff and chemical usage (Seo *et al.* 2023). This application aligns with sustainable farming practices, promoting optimal resource use and reducing the agricultural ecological footprint.

**Evaluation of effects of spray drift:** In the target zone, Nano DAP fertilizer applied at 1 m height and 3 m/s speed achieved droplet densities between 35–76 drops/cm<sup>2</sup> in *kharif* (2023), and 31–70 drops/cm<sup>2</sup> in *kharif* (2024) season (Zhang *et al.* 2020) due to close proximity to the surface. In the non-target zone, droplet densities ranged from 0–22 drops/cm<sup>2</sup> (mean:  $10 \pm 9.46$ ), with the highest density at D<sub>1</sub> and none at D<sub>3</sub> and D<sub>4</sub> (Wen *et al.* 2019, Zhang *et al.* 2020). This indicates significant horizontal drift reduction. In contrast, vertical drift calculations at distances of 0.5 m, 1 m, 1.5 m and 2m (V<sub>1</sub> to V<sub>4</sub>) from the target area showed droplet densities from 0–14 drops/cm<sup>2</sup> (mean:  $4.2 \pm 5.1$ ), highlighting effective targeting and minimal vertical drift (Lan *et al.* 2021). Table 3 and Fig. 3 illustrates the deposition and distribution of horizontal and vertical spray drift.

The application of nano DAP fertilizer using UAV technology in groundnut crops demonstrated high efficacy, achieving droplet densities of 35–76 drops/cm<sup>2</sup> in the target zone with minimal drift. Operating at a speed of 3 m/s and a height of 1 m, the UAV ensured uniform coverage across a 4 m swath, with non-target zone densities dropping to 0 at D<sub>3</sub> and D<sub>4</sub>, and a maximum of 21 drops/cm<sup>2</sup> at D<sub>1</sub>. Hybrid drone highlighted the VMD/NMD ratios ranging from 1.02–1.66 and droplet densities from 31–76

Table 3 Distribution and deposition of spray droplets in horizontal spray drift and vertical spray drift

Height, 1 m; Speed, 3 m/s.								
Sampling zone	Horizontal drift				Vertical drift			
	Drift sample distance (m)	Droplet density (drops/cm <sup>2</sup> )		Mean	Drift sample distance (m)	Droplet density (drops/cm <sup>2</sup> )		Mean
		Kharif (2023)	Kharif (2024)			Kharif (2023)	Kharif (2024)	
Target area	1	76	70	73	1	76	70	73
	2	54	57	56	2	54	57	56
	3	66	63	65	3	66	63	65
	4	53	45	49	4	53	45	49
	5	35	31	33	5	35	31	33
Non target	D <sub>1</sub>	22	20	21	V <sub>1</sub>	6	2	4
	D <sub>2</sub>	9	7	8	V <sub>2</sub>	6	14	10
	D <sub>3</sub>	0	0	0	V <sub>3</sub>	0	0	0
	D <sub>4</sub>	0	0	0	V <sub>4</sub>	0	0	0

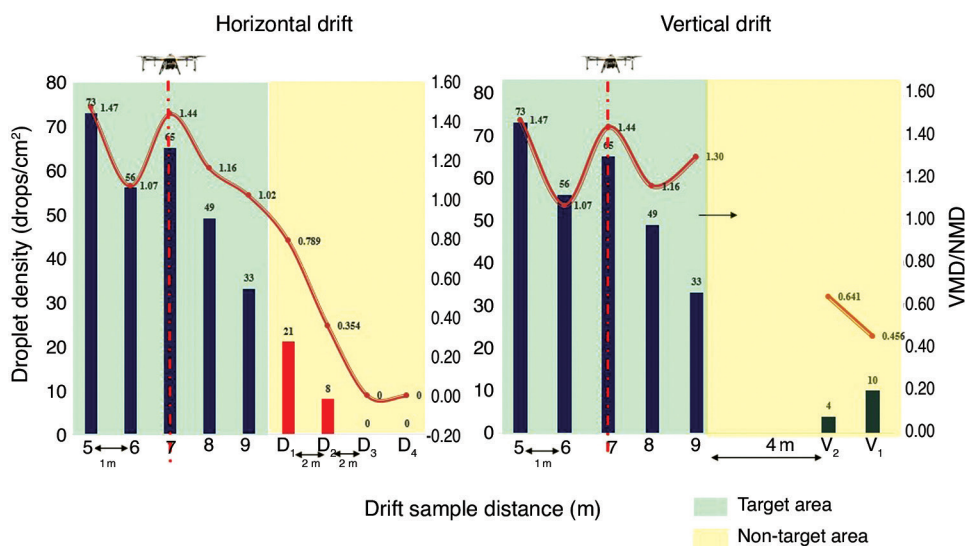


Fig. 3 Horizontal spray drift and vertical spray drift deposition and distribution. VMD, Volume median diameter; NMD, Number median diameter.

drops/cm<sup>2</sup>, demonstrating effective coverage with varied droplet sizes from very fine to ultra-coarse. This precision application minimizes environmental contamination and chemical runoff, enhancing soil and water conservation. The reduced frequency of applications lowers the carbon footprint and promotes ecological preservation, while also reducing soil compaction compared to traditional methods. The consistent droplet density measurements in the target area reflect the UAV's capability to maintain uniform spray deposition, essential for optimal nutrient distribution and crop health. The precise control over lateral drift and vertical dispersion further underscores the UAV's effectiveness in minimizing environmental impact and maximizing agricultural efficiency. Future research should focus on optimizing operational parameters, assessing long-term sustainability, and exploring scalability across various crops and conditions to continually improve this technology for

sustainable agriculture

*Limitations during the experiment:* The investigation was completed in the morning under clear, non-foggy weather conditions to ensure optimal retention of the applied inputs. Weather forecasts were taken into account, and factors such as cloudiness, light intensity, temperature, wind direction and air velocity were recorded prior to operating the UAV. The UAV was operated under specific conditions, including temperatures below 35°C, humidity levels below 70%, and wind speeds under 3 m/s. The experiment adhered to

the IS 17799:2022 standard procedures.

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