Standard Operating Procedure for Herbicide Application through Drones

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MESSAGE

Weeds continue to be the major threat to sustainable agriculture by reducing yields, deteriorating the quality of produce and increasing production costs. Conventional methods of herbicide application are labor-intensive, time-consuming, uneven coverage, require high spray volume, and associated with risks of environmental contamination and human exposure. The use of drone technology has opened new avenues for precision agriculture, offering site-specific, timely, and efficient application of herbicides. Drone-assisted herbicide spraying not only enhances operational efficiency and reduces chemical wastage but also minimizes risks to operators & environment, and improves accessibility in difficult terrains.

Drone-based herbicide application is a transformative technology directly contributing to Government of India's vision of *Viksit Bharat @2047*. The Ministry of Agriculture & Farmers Welfare, Govt. of India is promoting and supporting the use of drones through various schemes such as NAMO Drone Didi, Sub-mission on Agricultural Mechanization, Kisan Drone, etc. for spraying pesticides, custom hiring and cooperative use etc.

Recognizing the potential of Drone technology in weed management, the ICAR-Directorate of Weed Research, Jabalpur has developed a **Standard Operating Procedure (SOP) for Herbicide Application through Drone**. This document provides a structured framework covering planning, calibration, execution, and safety protocols to ensure uniformity, compliance, and environmental safeguards in herbicide use.

I am confident that this SOP would serve as a valuable reference for farmers, researchers, service providers, and regulatory agencies, enabling responsible adoption of drone-based herbicide application and contributing to sustainable, residue-free and profitable agriculture in India.

(M. L. Jat)

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New Delhi

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Foreword

Weed management using herbicides is becoming increasingly popular among the farmers due to their high efficacy and lower cost as compared to manual and mechanical methods. However, over-reliance and indiscriminate use of herbicides results in the evolution of herbicide resistance (HR) in weeds and environmental problems. The conventional methods of herbicide application using knapsack sprayer possess a high risk of herbicide exposure to the operators and are highly time-consuming and need high spray volume (400-500 litres of water/ha). The use of small unmanned aerial vehicle (UAV), commonly known as drone, is now being promoted by the Government of India for site-specific application of plant protection chemicals and nutrients to improve their efficiency and precision by allowing for accurate and uniform spray across the field, reducing overall herbicide use and thereby the environmental pollution.

Although the application of herbicides through drone provides better weed management, reduces chemical load, minimizes non-target exposure and promotes environmental sustainability, issues such as spray drift, dosage, selectivity & volatility of herbicides, and area coverage remain major challenges in its use. Since crops differ in canopy structure and cultivation practices, location-specific technologies and crop-specific Standard Operating Procedures (SOPs) are essential to ensure uniformity, safety, and compliance with regulatory norms. These SOPs define the correct nozzle selection, correct altitude, speed, and spray angle to ensure effective, economical, and eco-friendly herbicide application while avoiding chemical wastage, drift, and crop damage.

In context of promoting the use of drones for spraying herbicides in field crops for precise weed management, the ICAR-Directorate of Weed Research, Jabalpur has brought out "Standard Operating Procedure for Herbicide Application through Drones". I congratulate the authors for compiling this document and hope that the information contained herein will be useful to the farmers and other stakeholders involved in responsible use and promotion of drone technologies in herbicide application for weed management.

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PREFACE

Weed management is crucial in agriculture as weeds compete with crops for essential resources such as water, nutrients, light, and space, significantly reducing crop growth and yield. Uncontrolled weeds can cause yield losses exceeding 40-50% in some crops and increase production costs due to additional control measures. Besides competing with crops, weeds can harbour pests and diseases, further threatening crop health. Effective weed control improves crop quality, reduces harvest difficulties, and supports sustainable farming by minimizing soil erosion and maintaining soil fertility. Timely and integrated weed management ensures optimal crop productivity and profitability.

Traditional herbicide application methods suffer from lower precision, causing uneven coverage, chemical wastage, and increased environmental contamination. They are labour-intensive, slow, and less efficient, especially on large or difficult terrains. Heavy ground equipment leads to soil compaction and crop damage, while manual spraying exposes workers to harmful chemicals. Additionally, traditional machinery has difficulty accessing uneven or wet fields and involves higher operational costs due to fuel and maintenance.

The rapid advancement of drone technology has opened new frontiers in precision agriculture, offering an efficient, safe, and sustainable approach to weed management. Unmanned Aerial Vehicles (UAVs), or drones, enable site-specific herbicide application by optimizing spray coverage, reducing chemical wastage, and minimizing operator exposure to herbicides. However, accessibility to drones and related infrastructure may remain limited in several regions due to logistical, economic, or regulatory constraints. In contrast to conventional ground-based spraying methods, drone-assisted application provides the advantages of timely interventions, reduced labour dependency, and accessibility to difficult terrains, thereby enhancing overall efficiency in crop protection.

Recognizing the growing adoption of this technology in agriculture, it is essential to establish standard operating procedures (SOPs) that ensure uniformity, safety, and compliance with regulatory norms. This SOP provides a structured framework for planning, calibrating, executing, and documenting drone-based herbicide applications. It emphasizes correct nozzle selection, spray parameter optimization, drift management, and adherence to pre-harvest intervals (PHIs) and environmental safeguards.

The document has been developed to serve farmers, researchers, service providers, and regulatory agencies as a reference manual for responsible use of drones in herbicide application. By following these guidelines, stakeholders can maximize weed control efficiency while minimizing risks to humans, non-target organisms, and the environment.

This SOP further supports national goals of sustainable agriculture by promoting precision inputs, reducing chemical footprints, and aligning with residue-free production systems demanded by modern food supply chains.

(Authors)

Introduction

Indian agriculture has experienced rapid advancements recently, especially in research and the adoption of new technologies by farmers. Innovative methods like drip irrigation and mechanized systems for planting, harvesting, and grading are being effectively implemented in India, supporting sustainable agricultural practices. In recent years, drones are increasingly being used in agriculture and are being tested across the country for their suitability to Indian farming. Utilizing drones to spray pesticides for managing insect pests, diseases, and weeds has great potential as farming becomes more commercial and precise.

Weeds are among the major biotic constraints in sustainable food systems. They compete with crops for resources such as nutrients, moisture, solar radiation, and space. Besides causing direct yield loss, weeds serve as alternative hosts for insect pests, pathogens, and nematodes, posing a significant threat to food security, biodiversity, ecosystem services, and the health of humans and livestock. It has been estimated that in 10 major crops in India, the actual yield loss due to weeds amounts to USD 11 billion annually (Gharde *et al.* 2018).

In India, the majority of farmers are small and marginal with fragmented landholdings. Weeding is primarily done through manual and mechanical methods which are time consuming and costly. It has been estimated that on an average 25-30 man-days/ha is required for single manual weeding. However, if not integrated with pre- or post-emergence herbicides two hand weeding are necessary, especially during rainy season. It has been reported that India requires ~5 billion man-days of labour for single weeding (Rao *et al*. 2020). Rising labour wages and non-availability of adequate labour right at the time of the requirement are causing a serious problem to control weeds manually on a larger area in time. Hand-weeding or inter-row mechanical cultivation provides reasonable weed control. Mechanical weeding is generally more economical to use than the manual weeding. However, the effectiveness of mechanical weeding tools is highly dependent on weather and soil conditions. During the rainy season, there are not many clear days and as a result, inter-culture operations have to be delayed and this help the weeds to overtake the crops and cause severe yield loss. This method is applicable only in those crops that are sown in wider rows. Weeds grown within crop rows and nearer to crop plants are not controlled. Intra-row weeds cause much higher losses to crops than those growing between the crop rows (Melander *et al*. 2015). Partially uprooted weeds may regenerate and root injury to crops may also occur (Melander *et al*. 2018). The lower efficacy of intra-row weed control, damage to plant roots, requirement of skilled labour, high capital cost are the major limitations with mechanical weeding. Chemical weed management approaches have been found more effective and economical than manual and mechanical methods in reducing weed densities and biomass. However, over-reliance and indiscriminate use of herbicides results in the evolution herbicide resistance (HR) in weeds.

The effectiveness of herbicides largely depends on the efficiency of spraying equipment. In India, herbicides are sprayed either manually through knapsack sprayers or with the help of tractor-mounted sprayers where large quantity of herbicides and water are used and where a substantial proportion of spray goes waste in environment. In addition, manual spraying is labour intensive, time-consuming, and labour drudgery practice. In addition, application of pre-emergence herbicides through the conventional knapsack method immediately after sowing leads to an uneven crop stand due to pressing the seeds

Application of pre- and post-emergence herbicide by conventional sprayer

into the mud during herbicide application by spraying person (Vijayakumar *et al.* 2022). Moreover, conventional methods possess a high risk of pesticide exposure to the labour (Cao *et al.* 2017) and are highly time-consuming and need high spray volume (400-500 litres of water/ha) to cover the entire field.

Drones will make spraying crop protection chemicals more efficient by saving labour, time, water, and chemicals, while increasing the bio-efficiency of herbicides and reducing environmental pollution and human exposure to harmful chemicals. The Ministry of Agriculture & Farmers Welfare, Government of India, is promoting and supporting the use of drones for spraying pesticides, custom hiring, and cooperative use, making them easily available to farmers. Drones may also be linked with crop insurance to help manage farm losses and damages.

Key issues in herbicide spraying using drones

Use of drone technology in weed management supports precision agriculture, reduces chemical load, improves farmer profitability, and promotes environmental sustainability. They reduce overuse, minimize non-target exposure, and lower risks to the environment and human health compared to traditional spraying. Their efficiency depends on nozzle type, droplet size, spray coverage, and drift control. However, issues like volatility and spray drift (20–70% losses) remain major challenges, influenced by weather, equipment, and crop conditions. Since crops differ in canopy structure and cultivation practices, location-specific technologies and crop-specific standard operating procedures (SOPs) are essential. These SOPs define the correct altitude, speed, and spray angle to ensure effective, economical, and eco-friendly herbicide application while avoiding chemical wastage, drift, and crop damage. However, herbicide spraying by drones is more risky due to drift, selectivity, dosage, and coverage challenges. Herbicide spraying by drones has some special challenges compared to insecticides and fungicides. The key issues are:

Drift risk

- Herbicides can easily drift to nearby non-target crops due to wind and droplet size.
- Even small drift can cause crop injury, unlike insecticides/fungicides which usually have lower phytotoxicity.

Coverage requirement

- Herbicides often need uniform soil or foliar coverage to control weeds effectively.
- Achieving even coverage from a drone at height is more difficult compared to targeting pests/diseases on crop canopy.

Dosage sensitivity

- Weeds require a precise dose-overdose harms crops, under-dose fails to control weeds.
- Drones may produce uneven spray deposition, leading to variable effectiveness.

Tank mixture and volume

- Herbicides usually require higher spray volumes than insecticides/fungicides.
- Drone tank capacity is limited, so frequent refilling is needed.

Selectivity issues

- Many herbicides are crop-selective. Drift or misapplication can damage the crop itself.
- In contrast, insecticides and fungicides are generally safer to apply directly on crop canopy.

Regulatory and safety concerns

- Herbicide drift can cause disputes with neighboring farmers if their crops are affected.
- Hence stricter precautions and liability issues may arise.

The SOP for drone use in herbicide application includes rules on legal provisions, flying permissions, distance and weight limits, restrictions in crowded areas, drone registration, safety insurance, pilot certification, operation plans, flight zones, weather conditions, step-by-step operating procedures, and emergency handling.

Statutory provisions

Under the Insecticides Act, 1968 and Insecticides Rules, 1971, the Central Insecticides Board decides how herbicides are classified by toxicity and whether they are suitable for aerial use. Rule 43 (Chapter VIII) allows pesticide spraying by drones, with conditions:

Comparison showing the issues in drone application of herbicides vs insecticides/fungicides

Aspect	Herbicide (via Drone)	Insecticide/Fungicide (via Drone)
Drift risk	Very high – drift can damage nearby crops due to phytotoxicity.	Lower – drift usually does not harm crops, though may reduce efficacy.
Coverage requirement	Needs uniform foliar/soil coverage for effective weed control; difficult with drones.	Pest/disease targets are on crop canopy – drones can cover them more effectively.
Dosage sensitivity	Highly sensitive – small overdose can injure crops, under-dose fails to kill weeds.	Less sensitive – pests and pathogens are still controlled within a wider dose range.
Spray volume	Requires higher spray volumes; drone tank capacity is a limitation.	Needs comparatively less spray volume; drones fit well.
Selectivity	Many herbicides are selective; drift or misapplication can injure the main crop.	Most insecticides/fungicides are designed for direct crop application, safer for canopy.
Operational risk	High – wrong application can cause crop loss and farmer disputes.	Moderate – less risk of crop injury, mainly concerns about efficacy.
Regulatory/safety	Stricter regulations due to risk of off-target damage.	Easier acceptance since risks are lower.

- Operators must mark the spray area.
- Only approved insecticides and concentrations can be used, at approved heights.
- Washing, decontamination, and first-aid facilities must be provided.
- Local authorities and the public must be notified at least 24 hours in advance.
- People and animals not involved must be kept away during and after spraying.
- Pilots must be specially trained, including on health effects of insecticides.

Drone operations are permitted by the Ministry of Civil Aviation (MoCA) and the Director General of Civil Aviation (DGCA) through conditional exemptions. A new drone directorate in DGCA manages approvals and issues guidance on registration, permits, and procedures for drone use. Drone operations follow the Civil Aviation Requirements (CAR) under the Aircraft Act, 1934 and Aircraft Rules, 1937. The Unmanned Aircraft System (UAS) Rules, 2021 also apply. Operators must obtain:

- Unique Identification Number (UIN)
- Unmanned Aircraft Operator Permit (UAOP)

For agricultural spraying, any type of drone can be used if the UAOP specifically authorizes the discharge of herbicides.

The following details, precautions, pre-requisites etc. shall be adhered to before, during and post-operation:

Pre-application: Following do's and don'ts should be kept in mind while using drone spraying.

Do's for Drone spraying

1. Fly only in allowed areas (not near airports, military, or no-drone zones).
2. No permission is needed in green zones.
3. Use only Digital Sky compliant drones with “No Permission – No Takeoff” system.
4. Get a UIN from DGCA and display it on the drone.
5. Get a UAOP permit from DGCA for commercial use, if required.

6. Check the drone – it must be in good condition, leak-free, and safe for flying.
7. Fly only in visual line of sight (VLOS).
8. Operators must be trained in both drone handling and pesticide safety.
9. No alcohol uses within 8 hours before flying.
10. Calibrate spray system for correct nozzle output and dosage.
11. Fix a safe place for take-off, landing, and mixing pesticides.
12. Mark the treatment area, field boundaries, and obstacles (walls, trees, wires).
13. Assess crop type, growth stage, weed intensity, and field conditions.
14. Keep buffer zones between crops and non-target areas as per rules.
15. Avoid spraying near water bodies (at least 100 m away).
16. Inform local authorities (Gram Panchayat, Agriculture Officer, etc.) 24 hours in advance.
17. Keep people and animals away from the spray area for the specified time.
18. Record all flights and report accidents/incidents to DGCA/local police.

Don'ts for Drone spraying

1. Don't fly over crowds, public events, stadiums, or private property without permission.
2. Don't fly near airports without filing a flight plan and getting Airports Authority of India Air Traffic Control (AAI/ATC) clearance.
3. Don't drop or carry hazardous materials.
4. Don't fly from moving vehicles, ships, or aircraft.
5. Don't violate UAS Rules, 2021 or DGCA guidelines.

During application: Following safety & best practices need to be insured during drone spraying

- Read the label – follow all safety instructions.
- Wear PPE (gloves, mask, goggles, etc.).
- No eating, drinking, or smoking while spraying.
- Plan a proper flight route to reduce extra turns (Mark starting point and set boundaries).
- Fill drone tank with prepared spray solution (filtered to prevent nozzle clogging).
- Operators should stand downwind and with the sun at their back.
- Operate drone at:
  - Flight height: 2–3 m above canopy.
  - Speed: 3–5 m/s (depending on crop density).
  - Swath width: 3–5 m (varies with drone model).
- Test spray with clean water for 5 minutes before using herbicides.
- Use two-step dilution to dissolve herbicide fully.
- Set correct spray pressure for droplet size >100 µm.
- Overlap adjacent passes slightly (5–10%) for uniform coverage.
- Monitor spray quality (droplet size 100–200 microns recommended).
- Maintain line-of-sight with drone during operation.
- Check weather: Wind speed (not too high/low), Temperature (not extreme), Humidity (suitable for spraying)
- Maintain proper flying height, water volume and, flying speed

- Avoid walking through sprayed crops. Don't spray during bee activity; avoid drift to flowering crops.
- Follow label rules when pesticide is harmful to fish, birds, or silkworms.
- Use anti-drift nozzles to protect people and the environment.

Post-application

- Move the affected person to fresh air quickly.
- Rinse empty containers immediately.
- Keep waste to a minimum.
- Dispose of waste as per local laws.
- Do not burn or bury hazardous waste.
- Do not leave empty containers in the field; dispose of them as per Insecticides Rules, 1971.
- Put up warning signs in spray areas.
- Take a bath and wear clean clothes after spraying.
- Prevent leakage of herbicide during transport and storage.
- Store pesticides safely, away from people, animals, and food; clean up any spills right away.
- Maintain drones regularly as per manufacturer's schedule.

Critical parameters to be considered for Drone based herbicide application

Drone related

- Only DGCA-certified drones can be used for agricultural spraying. Certification ensures reliability.
- The drone should handle changing payloads (emptying tank) and provide a continuous spray swath at the minimum permitted height.
- It must have an accurate altitude sensor to keep the correct height above crops.
- GPS and map accuracy must be verified and used for safe geo-fencing around fields and obstacles.
- The spray system must allow variable flow control for uniform spraying.
- The drone must have fail-safes, such as Return-to-Home (RTH) when the tank is empty and auto-resume from the same point.
- The spray system should be leak-proof, with no dripping of herbicides (check before flight).

Herbicide related

- Use only CIB&RC-approved herbicides.
- Always follow the dose range as approved by CIB&RC.
- Check that the herbicide is compatible with the drone spray system for proper dilution, solubility, stability, and nozzle type. Follow CIB&RC rules if mixing more than one herbicide.
- Decide the minimum dilution to ensure good spray coverage both sideways and vertically.
- Dilute herbicides only with clean water or other ingredients approved by CIB&RC.

Environment limitations

Herbicide spraying through drone should be done only in suitable weather conditions, with proper wind speed (3–10 km/h -light breeze, no strong gusts), temperature (below 35°C), and relative humidity (50–80%) with no rainfall expected within 6–8 hours to ensure the best results.

Pilot training

- Only DGCA-certified pilots can fly agricultural drones.
- Pilots must complete mandatory training from authorized organizations on herbicide handling, drone operation, and crop protection guidelines.

Drift management-Critical operational parameters

Since most farms in India are small, spray drift from drones can affect nearby fields. To reduce drift, the following must be followed:

- Keep the right spray height above crops.
- Control the drone speed.
- Use suitable nozzles and correct droplet size.
- Mark a buffer zone with geo-fencing.
- Spray at the right time, avoiding rainfall periods.
- Follow other CIB&RC guidelines as updated.

Technical specification of the drone (UAV)

Particulars	Parameter
Category of drone	Small
Structure	Hexacopter structure
Flight modes	Fully autonomous, Semi-autonomous and Loiter mode
AIRCRAFT maximum take-off weight	24.9 kg
Diagonal wheelbase of frame	1200 mm
Folded size (Lx B x H)	762 mm * 762 mm * 483 mm
Maximum speed	8 m/s
Maximum height	10 meters
Maximum flight time	Up to 20 minutes (with payload)
Maximum hovering time	Up to 25 minutes (without payload)
Operating temperature range	0°C to 50°C
Spray tank volume	10 L
Max payload carrying capacity	10 kg
Return to launch (RTL)	Empty tank, Battery drained, Mission complete
Spraying capacity	Up to 8 acres/hour.
Battery fly time	Up to 20 minutes with payload
Spray in 20 minutes	1 hectare (2.5 acres)
Spray capacity per day (8 hours)	30 Acres with multiple battery sets
Nozzle type	Anti-drift, XR 11002VP (Extended range – Flat fan)
Nozzle quantity	4 pcs
Maximum spray speed per nozzle	0.85 L/min. (per nozzle for water)
Spray width	4 meters (4 nozzles, 1.5 m ~ 2.0 m above the crops)
Flying Range of GCS	Flies up to 5 km (LOS) using Ground Control Station
RADAR based collision avoidance	Detects tree, poles, wires, etc. in autonomous mode (22 meter) & re-route the path
RADAR based terrain following	Detects variable height of crop canopy and maintain constant spray height of 2 meter
Smart battery fails safe	The amount of energy left and return back to home (RTH)
Resume Mission	Autonomous resume mission within 50 cm accuracy
Live video streaming on GCS	2MP FPV Camera mounted on drone
Battery capacity	16,000 mAh (6S), 30C
Battery voltage	44.4 V (12S – 2 batteries connected in series)
Battery connector	AS150U / XT 90 (for heavy duty applications)
Battery charging time	30~ 40 minutes (Fast Charger – 1kw)

SOP for herbicide application through Drone in field crops

Drone spray parameter	Standard operating procedure	
Drone category	Small drone; Hexacopter	
Nozzle		
Nozzle type	XR 11002VP (Extended range – Flat fan)	
Nozzle tip material	Polymer with VisiFlo color-coding typically in yellow colour	
Number of nozzles	Four	
Nozzle operating pressure	15-20 PSI or 1.034-1.38 bar	
Nozzle discharge rate in single nozzle	0.454-0.908 lpm	
Nozzle angle	80°-110°	
Droplet size	226-325 VMD (microns)	
Spray width or swath	4.0 m	
Spray volume		
Pre-emergence herbicide	40 litres/ha	
Post-emergence herbicide	30-40 litres/ha	
Optimum flight height above crop canopy/target		
Pre-emergence herbicide	1.5 to 2.0 m	
Post-emergence herbicide	2.0 to 2.5 m	
Drone flying speed (m/s)		
For application rate 30 litres/ha	2.5-5.0 m/s	
For application rate 40 litres/ha	1.9-3.8 m/s	
During launch, RTL and turning	< 5.5 m/s	
Time of application		
Days after sowing (DAS)	Pre-emergence herbicide	0-3 DAS
	Post-emergence herbicide	15-20 DAS
Summer and rainy season	Morning session	6.00 am to 10.00 am
	Afternoon and evening session	3.00 pm to 6.00 pm
Winter season	Morning session	8.00 am to 11.00 am
	Afternoon and evening session	3.00 pm to 6.00 pm
Weather condition		
Temperature	< 35°C	
Humidity	> 50%	
Wind speed Minimum	> 0.56 m/s	
Wind speed Maximum	< 1.94 m/s	
During rain	Avoid spraying	
If visibility during fog/mist is not good	Avoid spraying	
Land topography		
Plain land	Use obstacle detection sensor to avoid trees, farm building, fencing, etc. to mitigate uneven application and missing plots	
Sloppy terrain	Use terrain following sensors for uniform application	
Length of buffer zone between plots		
For spraying height 1.5 to 2.0 m	5.0 m	
For spraying height 2.0 to 2.5 m	5.0-10.0 m (depending the wind condition)	
Field capacity		
Minimum	4.4 ha/day	
Maximum (with monocropping and larger fields)	11.6 ha/day	

Safe guarding the non-targets

To protect non-targets, follow these rules:

- Maintain a buffer zone between farms/crops as per CIB&RC guidelines to prevent spray drift.
- Keep the approved distance from the drone and avoid flying in the windward direction.
- Do not allow people or animals in the field during and right after spraying.
- Keep the approved distance from water bodies, houses, fodder crops, public places, dairy, poultry, etc., as per CIB&RC and DGCA rules.

Registration requirement of herbicides for drone applications

The registration of herbicides for drone use will change over time based on safety, effectiveness, and legal requirements, and will be published by CIB&RC. Drone users must use only CIB&RC-approved herbicides. To register a herbicide for drone use, applicants must apply to the CIB&RC Secretariat as per the Insecticides Act, 1968. Till date, three herbicides, viz. bispyribac-sodium @ 25 g/ha (as post-emergence) in rice, diclosulam @ 22-26 g/ha (as pre-emergence) in soybean and pyroxasulfone @ 127.5 g/ha (as pre-emergence) in wheat have been approved by the CIB&RC through drone application.

Different herbicides were tested across several crops and their performance was compared with the conventional knapsack sprayer (**Table 1**). In transplanted rice, application of bispyribac-sodium through drone resulted in 3.8–17.3% lower weed control compared to the knapsack, but grain

Table 1. Comparison of herbicide applications between drone and knapsack sprayer (results of multi-location trials)

Crop	Centre	Herbicide	Spray volume (L/ha)	Wind speed (km/hr)	Spray height (m)	% weed control over knapsack sprayer	% yield gain over knapsack sprayer
Transplanted rice	PJTSAU Hyderabad, GBPUAT Pantnagar, TNAU Coimbatore	Bispyribac-sodium 10% SC @ 25 g ai/ha	Drone: 25 Knapsack sprayer: 500	3.5-4.0	2 m	-17.3 to -3.8	-1.5 to 3.0
		Penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 135 g ai/ha				-8.9 to -3.71	-1.1 to 8.3
		Triafamone 20% + ethoxysulfuron l0% WG @ 66.5 g ai/ha				3.3	2.7
		Florpyrauxifen-benzyl 2.13% w/w + cyhalofop -butyl 10.64% w/w EC @ 150 g ai/ha				-0.9 to 27.43	-1.0 to 10.4
Direct seeded rice	IGKV Raipur	Penoxsulam + cyhalofop-p-butyl RM 135 g/ha PoE 20 DAS through drone	Drone: 25 Knapsack sprayer: 375	4.0	2 m	5.38	1.44
		Bispyribac- sodium 25 g/ha PoE 20 DAS through drone				10.07	2.67
		Florpyrauxifen 1.31 % + penoxsulam 2.1 % 40.63 g/ha spray with drone				7.94	1.04
Soybean	PDKV Akola	Diclosulam 26 g/ha	Drone: 25 Knapsack sprayer: 250	-	2 m	2.11	4.42
		Sulfentrazone 28% + clomazone 30% WP 725 g/ha				1.51	5.63
		Propaquizafop 2.5%+ imazethapyr 3.75% ME				-5.19	-4.51
Sorghum	RVSKVV Gwalior	Atrazine 750 g/ha (PE) *fb* 2,4-D Ethyl ester 500 g/ha as PoE (20 DAS)	Drone: 25 Knapsack sprayer: 450	-	2 m	7.63	5.6
		Atrazine 750 g/ha (PE) *fb* 2,4-D amine salt 750 g/ha as PoE (20 DAS)				1.98	0.86
		Atrazine + topramezone (TM) (500+18.9) g/ha				5.67	6.8
		Atrazine 500 g/ha *fb* mechanical weeding at 30 DAS				4.48	7.97

yield remained almost unchanged. However, herbicide mixtures such as penoxsulam + cyhalofop, triafamone + ethoxysulfuron, and florpyrauxifen-benzyl + cyhalofop achieved excellent weed control and produced higher yields than the knapsack sprayer. In direct-seeded rice, all tested herbicides performed better with drones as compared to knapsack. In soybean, pre-emergence herbicides showed superior performance with drones, whereas post-emergence herbicides were more effective with the knapsack. In sorghum, drone-applied herbicides provided better weed control and higher yields compared to knapsack application.

Key beneficial parameters based on multi-location experiments:

- Overall, the performance of drone application was comparable to the knapsack sprayer in terms of weed control and crop yield.
- Spray drift can be minimized by lowering the flying height of the drone during application.
- Drone spraying resulted in a 90–95% reduction in spray volume.
- It saved up to 85% of application time and reduced labour requirements by about 70%.
- Herbicide application can be resumed 2 hours after rainfall, provided there is a rain-free window of at least 6–7 hours following spraying.
- Drones enable coverage of larger areas in significantly less time.

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