

Drone Technology: Engineering Aerial Solutions for Precision Farming

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ABSTRACT

For Indian farming, agricultural drones (unmanned aerial vehicles, UAVs) are a game-changing engineering advancement that provides precision-based answers to pressing issues such as labour scarcity, input inefficiency and climate resilience. This review summarises verified research on drone applications in Indian agriculture from 2015 to 2026. It covers platform architecture, tried-and-tested techniques, economic impact, practical constraints and a strategic adoption roadmap. The Indian agricultural drone market, estimated to be worth USD 243.60 million in 2024, is expected to reach USD 2.11 billion by 2033 at a compound annual growth rate of 24.10 percent. In comparison with manual methods, field trials show a 40–50% reduction in pesticide use, a 20–40% reduction in fertiliser use and a ten-fold increase in operational speed. To guarantee fair access for India's 94 million smallholder farmers, a structured adoption framework is suggested, with a focus on custom hiring centres, skill development, indigenous engineering and artificial intelligence (AI) integration.

Keywords: *Unmanned Aerial Vehicles, Precision Agriculture, Agricultural Engineering, NDVI Mapping, Variable Rate Application, Kisan Drone Scheme, India*

1. Introduction

Indian agriculture is under unprecedented pressure from climate variability, shrinking landholdings (average 1.08 ha) and rising input costs. Erratic monsoons, heat stress and changing pest and disease dynamics make it increasingly difficult for farmers to rely on uniform, calendar-based management of irrigation, fertilisation and crop protection. At the same time, the availability of agricultural labour at critical periods such as sowing, spraying and harvesting has declined, as rural youth move towards non-farm employment. These pressures call for technologies that raise input-use efficiency while reducing drudgery and the health risks of manual operations. Precision agriculture offers data-driven pathways to this optimisation by matching the type, amount and timing of inputs to the actual variability of soil and crop conditions within a field. Within this framework, drones are becoming a versatile aerial platform for soil mapping, crop monitoring and spraying. Unlike satellites, they can be deployed on demand, fly below cloud cover and deliver centimetre-scale imagery, which is particularly valuable for the small and fragmented fields that characterise Indian farming. The technology has a long history. Fixed-wing agricultural aircraft were first used for dusting and spraying in the 1920s, but their cost and need for large, open fields restricted their use in India. After 2015, improvements in batteries, sensors and global navigation satellite systems (GNSS) accelerated the transition to contemporary multi-rotor UAVs that can hover, operate from small take-off areas and follow pre-programmed autonomous missions. Regulatory and policy support has followed. The Drone Rules 2021 liberalised the permissions framework, the Kisan Drone scheme provides subsidies of up to 75 percent for Farmer Producer Organisations (FPOs), and the Nam0 Drone Didi programme targets 14,500 Self-Help Groups (SHGs). Together, these measures are driving market expansion and establishing agro-drones as a mainstream farm technology. Against this background, the present review has three objectives: (i) to describe the engineering architecture of agricultural drones used in India; (ii) to

consolidate the verified evidence on their agronomic and economic performance, together with standard operating protocols; and (iii) to propose a phased adoption roadmap that addresses the particular needs of smallholder farmers.

2. Engineering Systems and Applications

2.1 Platform Architecture

In India, medium-class multirotor drones with a spray-tank capacity of 10–40 L are the most common type. This class offers a practical balance between payload, endurance and portability, and is well matched to the typical operating unit of a custom hiring service. The core engineering stack consists of lithium-polymer (LiPo) batteries of 12,000–30,000 mAh, brushless motors controlled by pulse-width modulation (PWM) of the electronic speed controllers, and flight controllers integrated with real-time kinematic (RTK) GPS, which delivers positioning accuracy better than 2 cm. This level of accuracy allows adjacent spray swaths to be flown with minimal overlap and gaps, and permits repeatable missions across crop seasons.

The sensor suite determines the range of agronomic information that can be collected. Red-green-blue (RGB) cameras provide visible imaging for stand counts, lodging assessment and field documentation. Multispectral sensors (typically five-band) record reflectance in the red-edge and near-infrared regions, from which indices such as the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Red Edge (NDRE) are computed. Thermal infrared cameras detect canopy temperature differences associated with water stress, and light detection and ranging (LiDAR) supports three-dimensional canopy modelling for biomass and structural analysis. In practice, spraying platforms and sensing platforms are often separate airframes, because the mass and vibration of a loaded spray tank are not compatible with precise imaging payloads.

2.2 Proven Applications with Indian Data

Crop health monitoring. UAV-derived NDVI maps show a strong relationship with ground-based chlorophyll measurements made with a SPAD meter, with coefficients of determination (r^2) of 0.85–0.92. Studies on Telangana cotton and Punjab wheat report 85–96% accuracy in the early detection of crop stress. Because NDVI responds to changes in canopy vigour before symptoms become visible to the naked eye, these maps give farmers and advisors a window in which nutrient deficiencies, water stress or pest outbreaks can be addressed before yield is affected.

Precision spraying. Trials by ICAR-CIPHET (2022) demonstrate that a drone can cover 1 ha in 7–10 minutes, compared with 4–6 hours by hand. Spray uniformity is also better, with a coefficient of variation (CV) of 18–22 percent for drones against 35–45 percent for backpack sprayers. Uniform deposition reduces both under-dosed patches, which allow pests to survive, and over-dosed patches, which waste chemicals and risk phytotoxicity. For Indian canopy conditions, centrifugal atomisers generate the ideal droplet size, with a volume median diameter (VMD) of 150–250 μm , which balances canopy penetration against drift. Beyond efficiency, drone spraying removes the operator from direct contact with pesticides, which is a significant occupational health benefit.

Economic impact. A Rajasthan case study (2023) illustrates the financial implications for farmers. By using drone services, the annual cost of fertilisers and pesticides on 30 bighas of land was lowered from ₹2 lakh to ₹25,000, a saving of 87.5 percent, alongside a 40–50 percent reduction in the quantity of chemicals applied. Such results show that precision application can improve profitability and lower the environmental load at the same time, although more multi-location, multi-season studies are needed to confirm how widely they can be generalised.

3. Methodological Framework

3.1 NDVI-Based Crop Monitoring Protocol

NDVI is widely used in precision agriculture to assess crop health, vigour and stress using satellite or drone imagery. The protocol followed in this review is summarised in Fig. 1 and proceeds in a logical sequence. It begins with the collection of satellite or drone imagery of the crop field at regular intervals. The images are then corrected for atmospheric effects, aligned and cleaned of noise to ensure radiometric accuracy. The NDVI formula, $(\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red})$, is applied to generate vegetation index maps, from which zones of healthy, stressed or sparse vegetation are identified across the field. These maps are integrated with soil, weather and yield data to provide deeper insights, and variable-rate input zones are defined for irrigation, fertilisation or pest control. Finally, NDVI trends are tracked across growth stages to evaluate crop performance and adjust practices. The overall aim is to help farmers make data-driven decisions on irrigation, fertilisation and pest management, ultimately improving yield and resource efficiency.

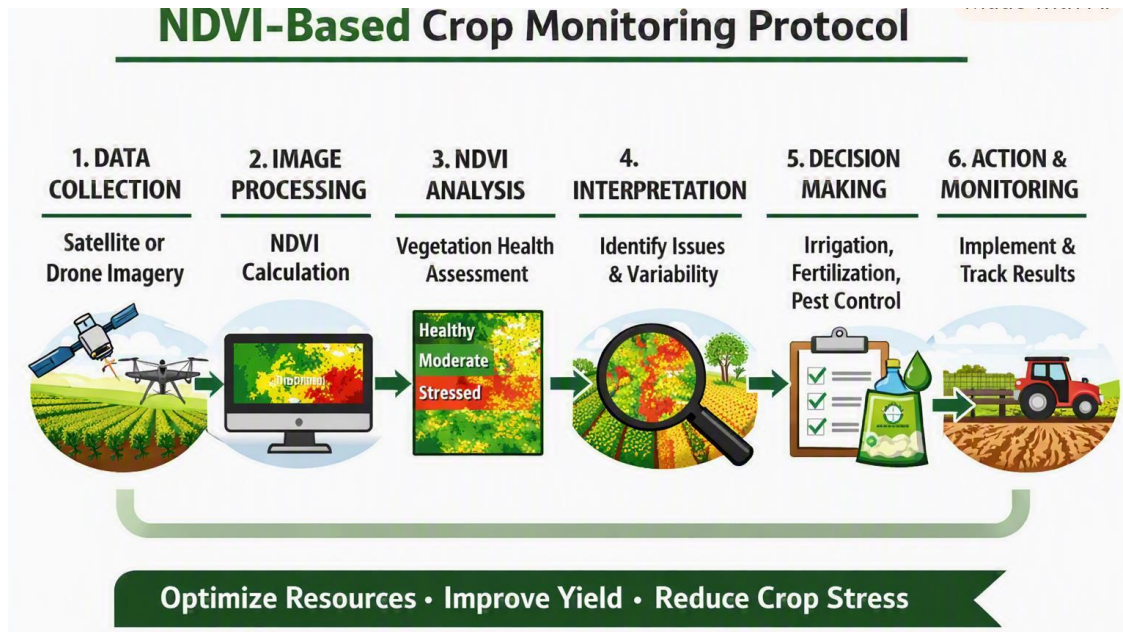


Fig. 1. NDVI-Based Crop Monitoring Protocol

Sources: open ai generated

The same workflow can be understood as a continuous cycle rather than a one-off exercise (Fig. 2). Data collection feeds data analysis, which informs input planning and resource application; crop mapping and evaluation then close the loop and provide the baseline for the next cycle. Fig. 3 shows examples of these precision applications in practice, with a drone imaging a field and a satellite-derived map delineating management zones.

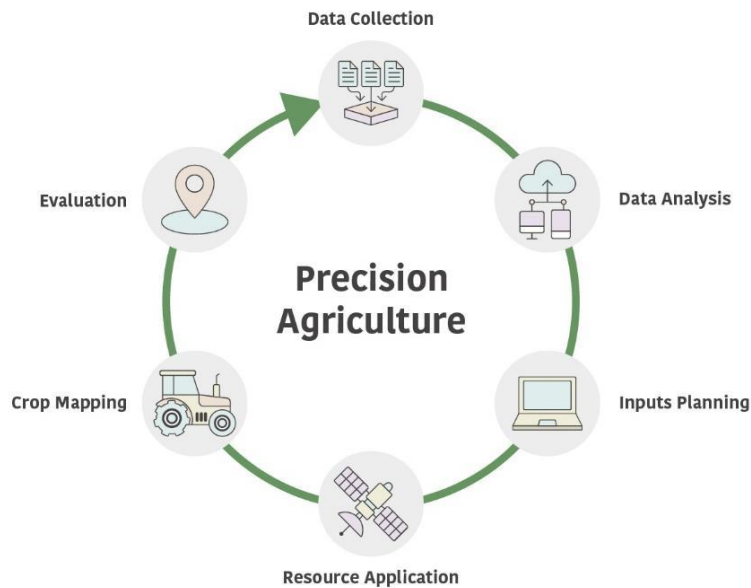
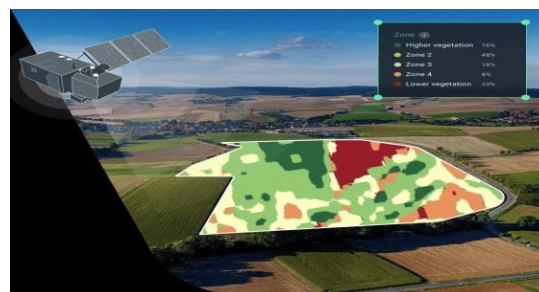


Fig. 2. The precision agriculture cycle

Sources: open ai generated



(a) Drone-based field imaging



(b) Satellite-derived zone map

Fig. 3. Precision applications in agriculture

Sources: open ai generated

The implementation of the protocol in the field follows five stages. In the planning stage, field shapefiles are imported into ground control station (GCS) software and the flight parameters are set. In the acquisition stage, autonomous multispectral imaging is carried out with reflectance calibration. In the processing stage, structure-from-motion (SfM) photogrammetry is used to generate orthomosaics and digital elevation models (DEMs). In the analysis stage, NDVI is computed and a threshold classification is applied. Finally, in the validation stage, ground-truth SPAD and leaf area index (LAI) measurements are collected at a minimum of 30 stratified sampling points so that the drone-derived maps can be verified against field conditions.

3.2 Spray Application Parameters

The optimised settings for drone spraying identified in the reviewed literature are as follows. The flying altitude should be maintained at 1.5–3.0 m above the canopy and the forward speed at 3–5 m/s to achieve uniform deposition. The effective spray width is 3–5 m, depending on the rotor downwash, and the target droplet density is 50–70 droplets/cm², as verified by water-sensitive paper assays. Under these settings, the effective field capacity is 1.36 ha/h, which is approximately ten times the manual rate. Altitude and speed interact strongly with wind conditions, canopy density and nozzle type, so these values should be treated as starting points to be calibrated for each crop and location.

For the experimental evaluation of drone spraying, a randomised complete block design (RCBD) with drone versus conventional sprayer comparisons is recommended. The primary metrics are percentage coverage, pesticide residue, crop yield and benefit–cost ratio, which together capture the biological efficacy, food-safety and economic dimensions of the technology.

4. Challenges and Constraints

Despite the encouraging evidence, several constraints must be addressed for the benefits of drone technology to reach smallholder farmers. The first is economic accessibility: the purchase cost of a spraying drone is beyond the means of an individual farmer holding about one hectare, which is why shared ownership and service-based models are central to adoption. The second is the skill gap. Safe and effective operation requires trained and certified remote pilots, as well as the ability to plan missions, maintain equipment and interpret imagery, and these skills are still scarce in rural areas.

Technical and operational limitations are also important. Battery endurance and payload capacity limit the area that can be treated per flight, and charging infrastructure and power supply in remote villages can be unreliable. Spray drift and the downwash of rotors need careful management, particularly in small, irregular fields and near sensitive neighbouring crops. In addition, pesticide labels and approved application methods have historically been written for conventional equipment, so clear guidance on registered products, doses and water volumes for aerial application is required. Finally, the evidence base itself is uneven: many trials are short-term, crop-specific or confined to a single location, which underlines the need for standard protocols and farmer-centric validation across agro-climatic zones.

5. Strategic Roadmap for Indian Farmers

5.1 Immediate Actions (2026–2028)

In the immediate term, the priority is to build the service and skills infrastructure. Under the Sub-Mission on Agricultural Mechanization (SMAM), one drone Custom Hiring Centre (CHC) should be set up for every cluster of five panchayats, so that small farmers can obtain drone services on demand without owning the equipment. A sustainable service rate of ₹400–600 per acre is feasible when compared with input savings of ₹1,200–2,000 per acre, leaving a clear net benefit to the farmer while keeping the CHC viable.

Skill development should be pursued through the Pradhan Mantri Kaushal Vikas Yojana (PMKVY), by incorporating the DGCA Remote Pilot Certificate training into Krishi Vigyan Kendra (KVK) and State Agricultural University (SAU) extension programmes aimed at rural youth aged 18–35 years. This would simultaneously create rural employment and a local pool of qualified operators. In parallel, standard protocols are needed: through open access on the e-NAM platform, ICAR should develop crop-specific NDVI threshold tables for 20 major crops across 15 agro-climatic zones, so that image interpretation is consistent and transferable.

5.2 Medium-Term Initiatives (2028–2031)

In the medium term, the emphasis shifts to indigenous engineering and intelligent services. Incentives under the Production Linked Incentive (PLI) scheme should encourage drones designed for Indian conditions, such as small irregular fields (< 0.5 ha) and narrow row spacing, while Department of Science and Technology (DST) and Department of Biotechnology (DBT) financing should support research and development (R&D) centres in academia and industry. Local manufacturing can lower costs, improve availability of spare parts and shorten repair times.

AI integration is the second pillar. Within 24 hours of a survey, drone data pipelines should be linked to AgriStack and Kisan e-Mitra to deliver advisories in vernacular languages, converting raw imagery into actionable recommendations that farmers can understand. A third initiative concerns climate-smart applications. A measurement, reporting and verification (MRV) framework should be created for drone-enabled emission reductions under the LiFE carbon credit programme, since a 20–40% reduction in fertiliser use translates into nitrous oxide (N₂O) mitigation and could open an additional income stream for farmers.

5.3 Long-Term Vision (2031–2036)

The long-term vision is the creation of smart village clusters: integrated farm intelligence networks that combine drones, Internet of Things (IoT) sensors, weather stations and market application programming interfaces (APIs), to be piloted in 50 aspirational districts. Such clusters would allow sensing, advisory, input application and marketing decisions to be coordinated at village scale. To ensure that these developments remain grounded in farmers' realities, all drone protocols should undergo mandatory Participatory Rural Appraisal (PRA) validation through KVK On-Farm Trials (OFTs) and Front-Line Demonstrations (FLDs) before recommendations are scaled up.

6. Conclusion

This review shows that, with proven efficiency gains in spraying, monitoring and mapping applications, agro-drone technology has moved from the experimental to the operational stage in Indian agriculture. The reviewed evidence indicates that drones can reduce pesticide use by 40–50% and fertiliser use by 20–40%, cover fields many times faster than manual methods, and deliver more uniform application, while also reducing farmers' exposure to agrochemicals. Multispectral imaging adds a diagnostic dimension, since NDVI maps correlate strongly with ground-measured chlorophyll and permit early detection of crop stress, which supports timely and site-specific decisions.

However, for smallholder farmers, economic accessibility and skill gaps continue to be major obstacles. High equipment costs, the need for certified pilots, limited battery endurance, uncertainty over approved aerial-application practices and the scarcity of region-specific, multi-season evidence all restrict the pace at which benefits can be shared. The suggested roadmap offers a methodical route for fair adoption. In the near term it relies on custom hiring centres and rural-youth skilling; in the medium term on indigenous engineering, AI-enabled vernacular advisories and carbon-credit pathways; and in the long term on smart village clusters supported by farmer-centric validation.

Several research priorities follow from this analysis. These include long-term, multi-location trials on diverse crops and cropping systems; crop-specific NDVI thresholds and prescription-map algorithms suited to small fields; low-cost, lightweight platforms designed for Indian conditions; drift-mitigation and nozzle-selection studies; and rigorous techno-

economic and life-cycle assessments that include environmental co-benefits. With convergent institutional action and a supportive policy architecture, India can lead the Global South in drone-enabled precision farming, improving productivity, sustainability and farmer livelihoods all at once.

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