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Role of agriculture drones in India for enhancing efficiency and potentials using nano fertilizers for the benefits of farmers: A case study

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Abstract
In India, agricultural drones are increasingly being adopted as precision farming tools that enhance efficiency and sustainability by enabling uniform, site-specific application of nano-fertilizers, reducing input wastage, labor dependency, and production costs, while improving crop health and productivity. Agricultural drones, a class of small unmanned aerial vehicles (UAVs), are effective tools in crop cultivation for fertilizer and pesticide application, crop monitoring, and real-time data acquisition. Their high operational speed ensures rapid and uniform field coverage, with minimal human exposure to agrochemicals. Nano-fertilizers, owing to their nano-scale particle size and high surface area, improve nutrient absorption, photosynthetic efficiency, and metabolic activity in plants. In the present case study, drone-assisted application of nano-fertilizers significantly outperformed conventional farmer practices, with the combined use of recommended basal fertilizers and foliar nano urea (T_2) resulting in higher plant height, leaf area, stem girth, and fresh and dry biomass, indicating improved nutrient uptake and growth efficiency in crops, while the integration of nano DAP with nano urea (T_3) further enhanced phosphorus use efficiency and vegetative development. Although the cob number remained unchanged during the observation period, increased biomass under nano-fertilizer treatments suggests higher yield potential at later growth stages. Drone-based spraying enabled precise and timely nutrient delivery, reducing fertilizer use by approximately 20-40%, achieving significant savings in labour and operational costs, and lowering chemical exposure risks. The technology also improved application efficiency by covering about one ha in 20 minutes using nearly 25 Liters per hectare of water, thereby reducing water consumption, input losses, and cost per acre.Overall, drone-based nano-fertilizer application proved to be a cost-effective, resource-efficient, and environmentally sustainable approach for precision crop production, particularly benefiting small and marginal farmers.

Keywords: Agricultural drones, UAV, drone spraying, nano-fertilizers, precision agriculture, growth assessment

Introduction
The present case study is based on a project titled "Demonstration of Agriculture Drones to Create Awareness and Optimize the Resources for the Benefit of Farmers**,"** implemented atKrishi Vigyan Kendra (KVK), Ranga Reddy**,** under ICAR-Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, Telangana**,** with financial support fromM/s Indian Farmers Fertiliser Cooperative Limited (IFFCO), New Delhi**.** The project was conceptualized to address the limitations of traditional input application methods and to demonstrate the practical effectiveness of drone-based technologies integrated with nano-fertilizers under real field conditions.
Field demonstrations were conducted across different villages of Ranga Reddy district during the Kharif and Rabi seasons of 2023-2025, covering a total area of 500 acres. The study involved multi-location demonstrations at three locations on major crops, including paddy (175 acres), cotton (175 acres), maize (100 acres), and vegetable crops (50 acres). Drone-based spraying was systematically compared with conventional power sprayer application to assess differences in operational efficiency, crop performance, and input utilization. Comprehensive observations were recorded on crop growth parameters, pest and disease

incidence, crop yield, quantity of fertilizers and pesticides used per acre, and cost of spraying per acre. The experiment comprised four treatments (T_1, T_2, T_3, and T_4) representing different fertilizer compositions and drone-based application strategies, with a specific focus on evaluating nano-fertilizer performance.

The rapid advancement of agricultural drone technology has led to its increasing integration into both modern and conventional farming systems. Continuous improvements in unmanned aerial vehicle (UAV) design, flight control systems, and sensor integration have enabled agricultural drones to perform diverse farm operations with high precision and reliability (Yallappa *et al.*, 2024) [24]. Recent developments in small quadrotor UAVs equipped with inertial measurement units (IMUs) and sensor-based control systems have enhanced flight stability and operational accuracy, expanding their application in crop monitoring, field surveillance, irrigation management, and precision input application. The adoption of drones allows farmers and trained operators to conduct timely and site-specific field operations, reducing dependence on manual labour and conventional machinery, which is critical in the context of rising food demand, labour shortages, and climate-induced production challenges (Makam *et al.*, 2024) [11].

Among various applications, drone-based spraying has gained prominence due to its ability to ensure uniform and precise application of fertilizers and crop protection chemicals while minimizing human exposure to agrochemicals, reducing water use, saving time, and improving operational efficiency (Komatineni *et al.*, 2024) [8]. In the present study, the agricultural drone operated at a rotor speed of 5000-6000 rpm under fully loaded conditions and 1800-2000 rpm with an empty tank, powered by a 24,000 mAh lithium battery (AC-DC), and was deployed under standardized operating conditions in accordance with ISO and BSO guidelines, with wind speed below 3 m s^{-1}, ambient temperature ranging from 15 to 35 °C, and relative humidity between 40 and 70%.Precise input delivery reduces wastage, chemical runoff, and environmental contamination, thereby enhancing crop productivity and land-use efficiency (Kumar *et al.*, 2021; Chandak *et al.*, 2025) [10, 4]. In parallel, nano-fertilizers such as nano-urea (liquid) and Nano (Liquid) DAP have emerged as efficient alternatives to conventional fertilizers due to their nano-scale particle size, high surface area, and superior nutrient use efficiency (Gupta *et al.*, 2025; Gao *et al.*, 2024) [12, 13]. Nano-urea facilitates controlled nitrogen release through enhanced foliar absorption, improving photosynthetic efficiency, crop growth, and stress tolerance, while reducing nitrogen losses. Similarly, Nano DAP, notified under the Fertilizer Control Order (FCO, 1985) in 2023, enhances nitrogen and phosphorus availability through efficient penetration and assimilation, leading to improved crop growth, yield, and quality with reduced environmental losses (Samui *et al.*, 2022; Siatwiinda *et al.*, 2021; Sahni *et al.*, 2025) [17, 18, 16].

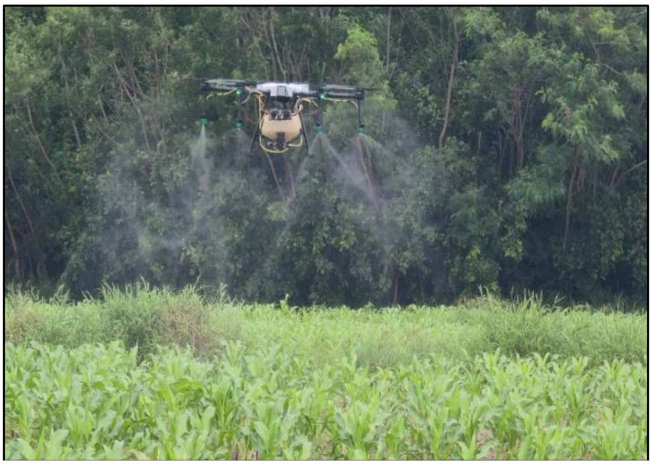
The integration of agricultural drones with nano-fertilizers represents an effective precision nutrient management strategy, ensuring uniform distribution, optimal dosage, and timely application synchronized with crop growth stages (Reddy *et al.*, 2022; Gatkal *et al.*, 2025) [15, 6]. This approach improves nutrient use efficiency, lowers input costs, and minimizes environmental pollution, supporting sustainable and climate-resilient farming systems (Ramesh *et al.*, 2024) [14]. Recognizing the potential of drone technology in agriculture, the Government of India is actively facilitating its adoption through several initiatives. The NAMO Drone Didi Scheme aims to empower 15,000 women's self-help groups (SHGs) by providing an 80% subsidy (up to ₹8 lakhs) to offer drone rental services to local farmers. The Sub-Mission on Agricultural Mechanization (SMAM) provides a 100% subsidy to research institutions and a 40-50% subsidy to individual farmers for drone procurement. Additionally, Custom Hiring Centers (CHCs) enable farmers, particularly small and marginal ones, to access drones on a rental basis, ensuring inclusive dissemination of this technology (Srivastava *et al.*, 2019; Bhat *et al.*, 2024) [19, 2].

In this context, the present case study aims to generate scientific evidence and practical insights into the role of agricultural drones combined with nano-fertilizers in enhancing input-use efficiency, reducing labour dependency, improving economic returns, and accelerating the adoption of precision agriculture technologies in Indian agriculture.

Objectives of the study

1. To conduct drone demonstrations to showcase the manual fertilizer application to drone-assisted nano fertilizer spraying in crops.
2. To evaluate the effectiveness and efficiency of different drone spraying operations on crop productivity.
3. To raise awareness among farmers about the potential of drone technologies in agriculture.

Transition from manual fertilizer application to drone-assisted nano fertilizer spraying in crops.



Source: Experiment conducted by CRIDA-KVK-Rangareddy dist

Fig 1: Spraying of nano-fertilizers in a maize crop using agriculture drone

Materials and Methods

The research was conducted in CRIDA-KVK and adopted villages of Rangareddy district, Telangana, India, during the Kharif season (2024-2025). The selected study area represents diverse agro-climatic and farming conditions. Villages were chosen based on cropping pattern, farm size, and susceptibility to major agricultural challenges, including pest incidence, water stress, and inefficient use of agricultural inputs. The study aimed to evaluate the effectiveness of drone-based interventions under real field conditions.

Drone Technology and Equipment
Drone-based operations were carried out using an agricultural spraying drone with the following specifications:

- Drone model: Agribot (Registration No.: IA6A1123C1800310)
- Type: Hexacopter
- Payload capacity: 10 kg
- Flight endurance: Up to 20 minutes per fully charged battery set

The drone was equipped with precision spraying nozzles and automated flight control systems to ensure uniform application and accurate targeting of agricultural inputs.

Drone Replications and Experimental Design
Drone treatments were conducted over a period of three months in the adopted villages of Rangareddy district and at theCRIDA KVK. Multiple replications were carried out to assess the consistency and effectiveness of drone-based interventions across different crop growth stages.

Fertilizer Application Using Drones
For drone-based fertilizer application, IFFCO nano fertilizers were used. The fertilizers were applied as foliar sprays using the drone, following recommended dosages. The details of fertilizer quantity and spray volume per acre are presented in Table 1.

Table 1: Dosage of nano fertilizers applied using a drone

S. No.	IFFCO Nano Fertilizer	Fertilizer quantity per acre in ml	Water quantity per acre in litres
1	Urea	500	10
2	DAP	500	10
3	Terpaz	50	10
4	Surfafur	10	10

Applications of Drones in Indian Agriculture
Precision Agriculture
Drones enable precision agriculture, which involves using data to optimize farming practices. With the help of drones, farmers can monitor crop health in real-time, detect pest infestations, and assess soil moisture levels. This data allows farmers to make informed decisions regarding irrigation, fertilization, and pest control, reducing the need for excessive chemical inputs and enhancing crop yield (Song *et al.*, 2024; Tzounis*et al.*, 2017).

Improved Crop Management
Drones equipped with high-resolution cameras and multispectral sensors can capture detailed images of fields, providing valuable information about crop growth, nutrient deficiencies, and disease outbreaks. This allows farmers to take targeted action, such as applying fertilizers or pesticides only where needed, improving efficiency and minimizing environmental impact (Symeonaki*et al.*, 2020).

Cost-Effective and Time-Saving
Drones significantly reduce the time and labor required for various agricultural tasks. For instance, aerial spraying of fertilizers and pesticides takes a fraction of the time compared to manual or tractor-based spraying. This reduces labor costs and increases efficiency, especially in regions with labor shortages or high labor costs (Komatineni*et al.*, 2024) [8].

Improved Irrigation Management
Water scarcity is one of the most pressing issues faced by Indian farmers. Drones can be equipped with thermal sensors to assess soil moisture levels and identify areas that require irrigation. This allows for more efficient use of water, reducing wastage and improving water management practices, which is crucial for sustainability in the face of climate change (Berni *et al.*, 2009) [1].

Increased Yields and Reduced Input Costs
By enabling more precise application of inputs such as fertilizers, pesticides, and water, drones help reduce costs associated with overuse of these inputs. This not only reduces the environmental footprint but also increases crop yields, as plants receive the right amount of nutrients and care at the right time (Makam *et al.*, 2024) [24].

Monitoring of Large Areas
India's agricultural landscape is vast, and managing large fields can be a logistical challenge. Drones can quickly cover large areas, providing a bird's-eye view that allows farmers to assess their fields comprehensively. This can be especially beneficial for large-scale farms or cooperatives, as drones provide real-time updates and insights without the need for ground-based inspections (Ramesh *et al.*, 2024; Makam *et al.*, 2024) [14, 24].

The Role and Potential Benefits of Agricultural Drones
Agricultural drones in India will serve as a transformative force for small and large-scale farmers, especially when combined with nano-fertilizers to optimize nutrient delivery and crop yields. This synergy will address historical challenges such as labor shortages, uneven chemical application, and significant resource wastage.

Drones offer key advancements in precision agriculture
Precision Spraying: Drones deliver fertilizers with pinpoint accuracy, reducing overall chemical usage by 20-50% (Kumar *et al.*, 2023) [9].

Time Efficiency: Drones can cover an area of 10 acres in under an hour-a task that typically takes up to two days for manual labourers (Srivastava *et al.*, 2019) [19].

Water Conservation: Drone-based spraying reduces water consumption by 80-90%, requiring only 5-10 liters per acre compared to the 100 liters typically needed with traditional methods (Berni *et al.*, 2009) [1].

Health and Safety: Automating the spraying process reduces direct human exposure to hazardous chemicals, decreasing pesticide-related illnesses among the rural workforce.

The Efficiency of Nano Fertilizers in Drone Systems
Nano fertilizers (e.g., Nano Urea, Nano DAP) are specifically designed for efficient absorption at the cellular level:

Higher Absorption Rate: In an experiment conducted in 2023-24 and 2024-25 in the adopted villages of KVK Ranga

Reddy in Telangana, it was found that Nano Urea sprayed by drones increased nitrogen absorption efficiency from ~50% (manual) to over 80% (Castaldo *et al.*, 2023) [3].

Increased Productivity: Field trials have demonstrated that the use of nano fertilizers in crops such as rice, maize, cotton and tomatoes increases average yields by 8-25% (Castaldo 2023) [3].

Cost Savings: A 500 ml bottle of Nano Urea, priced at approximately ₹240, serves as an alternative to a traditional 45 kg bag of urea priced at ₹267, while also reducing transportation and storage costs (Yallappa *et al.*, 2024) [24].

Problems and Challenges faced with agricultural drones

High Initial Investment and Maintenance Costs

One of the primary challenges of adopting drone technology in Indian agriculture is the high initial investment required to purchase drones and related equipment. The cost of drones equipped with advanced sensors and cameras can range from tens of thousands to several lakhs of rupees, making them unaffordable for small and marginal farmers. Additionally, maintenance and operational costs, including pilot training and repairs, can further strain farmers' budgets (Jain *et al.*, 2023; Gatkal*et al.*, 2025) [7, 6].

Limited Awareness and Knowledge

While drones hold significant potential, the awareness and knowledge about drone technology among Indian farmers remain limited. Most farmers are not familiar with how drones can benefit their crops or how to operate them effectively. The lack of technical skills and training among farmers is a major barrier to widespread adoption (Wonde *et al.*, 2022) [23].

Regulatory and Legal Issues

The use of drones in agriculture in India is subject to regulatory oversight by the Directorate General of Civil Aviation (DGCA). As of now, drone use in India is heavily regulated, with requirements for drone pilots to obtain licenses and adhere to specific guidelines regarding altitude, no-fly zones, and airspace management. The regulatory framework for agricultural drones is still evolving, and the complexity of these regulations can create barriers to entry for farmers (Srivastava *et al.*, 2019; Bhat *et al.*, 2024) [19, 2].

Connectivity and Infrastructure Limitations

India's rural areas often face challenges in terms of internet connectivity and infrastructure, which are crucial for the operation of drones (Song *et al.*, 2024) [20]. Drones rely on stable GPS signals, real-time data transmission, and cloud storage to operate effectively. In areas with poor connectivity, the full potential of drones may not be realized, limiting their effectiveness (Yallappa *et al.*, 2024) [24].

Climate and Weather Conditions

Indian agriculture is highly dependent on weather patterns, which can be unpredictable. Drones are vulnerable to adverse weather conditions such as high winds, rain, and extreme temperatures, which can affect their performance and reliability. In addition, the short battery life of drones limits their operational capacity, particularly in large-scale farms or fields with irregular terrain (Gao *et al.*, 2021) [5].

Results and Discussions

The Results and Discussion section presents a detailed comparison between conventional farmer practices and drone-based spraying. The study was conducted on maize fields using agricultural drones for the application of IFFCO nano-fertilizers, with three replications to ensure experimental reliability. The total experimental area covered 2,700 m², with each plot measuring 540 m². This experimental design enabled an effective evaluation of the performance of drone spraying in comparison to traditional fertilizer application practices under field conditions.

Overall Comparison of Treatments (Before vs. After Drone Spraying)

Overall, the comparison clearly demonstrates that before drone-based nano-fertilizer spraying (T_1), maize crops exhibited lower growth uniformity, reduced biomass accumulation, and inefficient nutrient utilization. After drone spraying, particularly under T_2, crops showed substantial improvement in growth parameters, nutrient-use efficiency, and physiological performance.

Among all treatments, the performance ranking was $T_2 > T_3 > T_1 > T_4$. The results confirm that drone-assisted nano-fertilizer application, especially nano urea alone or in combination with nano DAP, ensures uniform nutrient delivery, reduces nutrient losses, and enhances crop growth without altering plant population or cob initiation. In contrast, treatments without nano-fertilizer supplementation (T_4) failed to achieve comparable improvements, highlighting the importance of nano-fertilizers in maximizing the benefits of drone-based spraying.

Conclusion

This study conclusively demonstrates that drone-assisted nano-fertilizer spraying significantly outperforms conventional farming practices in maize cultivation. Before drone spraying, crops under traditional fertilization showed comparatively lower growth, biomass accumulation, and nutrient-use efficiency. After drone-based application of nano fertilizers, particularly nano urea combined with recommended basal fertilizers, maize crops exhibited marked improvements in plant height, leaf area, stem girth, and fresh and dry biomass across growth stages.Precision spraying via drones delivers fertilizers with pinpoint accuracy, reducing overall chemical usage by 20-50%. The time efficiency with drones allows for covering a 10-acre area in less than a hour-a task that typically takes up to two days for manual labourers. Water conservation in drone-based spraying reduces water usage by 80-90%, requiring only 5-10 liters per acre compared to the 100 liters typically needed with traditional methods. Increased productivity due to field trials has proven that the use of nano-fertilizers in crops such as rice, maize, cotton, and tomato increases average yields by 8-25%.Through the efficient use of resources, fertilizer wastage was reduced by 40%, the economic impact showed a significant reduction in investment costs and a 20% increase in crop yield, and sustainability aspects included reducing the flow of chemicals into local water sources and promoting long-term soil health.Drone-assisted nano-fertilizer application emerges as a transformative and environmentally responsible technology for modern agriculture in India.

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