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Review

A Promising and Forward-Looking Advancement Using Drones: Perspectives from Indian Sericulture

Haragopal Dutta [1], Suman Dutta [2], Harendra Yadav [1], Immanual Gilwax Prabhu [3], Arnab Roy [4], Narisetty Balaji Chowdary [1,3,4] and Sumanta Das [5,*]

[1] Farm Management and Agroforestry Section, CSB-Central Tasar Research and Training Institute, Ranchi 835303, Jharkhand, India; haragopalbckv@gmail.com (H.D.); drharend@gmail.com (H.Y.); chowdarynb21@gmail.com (N.B.C.)

[2] Department of Genetics and Plant Breeding, Ramakrishna Mission Vivekananda Educational and Research Institute, Kolkata 700103, West Bengal, India; duttasumansiliguri@gmail.com (S.D.)

[3] Silkworm Improvement Section, CSB-Central Tasar Research and Training Institute, Ranchi 835303, Jharkhand, India; immanual.gilwish@gmail.com (I.G.P.)

[4] Project Monitoring Coordination and Evaluation Cell, CSB-Central Tasar Research and Training Institute, Ranchi 835303, Jharkhand, India; royarnab_94@rediffmail.com (A.R.)

[5] School of Environment and Disaster Management, Ramakrishna Mission Vivekananda Educational and Research Institute, Kolkata 700103, West Bengal, India

* Corresponding author. E-mail: sumanta.das@uq.net.au (S.D.)

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ABSTRACT: Drone integration in sericulture marks a promising advancement within the sector, leveraging recent technological strides in unmanned aerial vehicles (UAVs) across various industries like agriculture and healthcare. While the adoption of drones in sericulture remains nascent, their potential benefits, particularly in chemical spraying tailored to sericulture's unique environmental conditions, are increasingly recognized. This paper explores the efficacy of drone-based pesticide spraying and smart fertilization methods optimized for sericulture settings. The rapid deployment capabilities of drones facilitate enhanced network connectivity, potentially catalyzing rural development and economic prosperity within the sericulture community. However, ethical and operational concerns persist regarding drone use across industries, necessitating robust regulatory frameworks and ethical guidelines. Furthermore, advancements in artificial intelligence augment drone capabilities, enabling automated inspections and improved performance across diverse applications. This paper underscores the need for further research and the development of standardized operating protocols to harness the transformative potential of drone technology in sericulture. Key focus areas include optimizing pesticide delivery, ensuring environmental sustainability, and addressing ethical considerations surrounding drone utilization. By leveraging UAVs for precision spraying and smart fertilization, sericulture stands poised to enhance productivity, bolster economic development, and navigate emerging challenges in agricultural production.

Keywords: Unmanned aerial vehicles; Artificial intelligence; Pesticide; Precision spraying; Sericulture; Smart fertilization

1. Introduction

Unmanned aerial vehicles (UAVs), also referred to as drones, are a class of aircraft that can travel without a pilot present. They can be remotely controlled by an operator or follow a pre-programmed flight path autonomously.1]. Drones have been employed in several industries, including agriculture, cartography, and the military. Drones have been utilized in agriculture to monitor the growth of trees and cattle and to control weeds, pests, and diseases. Drones are employed in precision farming to detect plants remotely, replacing satellites and airplanes. Drone technology provides inexpensive aerial plant monitoring for farmers [2]. Due to declining cultivated land, a labor shortage, and antiquated conventional methods, drones have become increasingly popular in agriculture [3]. Field monitoring can be completed more quickly and accurately with the use of a drone, which can also gather more information. In addition to monitoring crops, drones can now be used to transport payloads, such as pesticide and herbicide applications [4]. As a

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result, this technique can improve spraying efficiency and lessen the labor scarcity. Additionally, there is a chance of lessening the chance of herbicide and chemical poisoning [1]. Though the technology is not new, it is novel in sericulture, especially in tasar culture.

For example, drone technology was demonstrated at CSB-CTRTI in Ranchi, capturing attention and inspiring innovation. The demonstration illuminates the potential for widespread adoption and advancement in the field (Figure 1).

Figure 1. Spreading through drone technology demonstration at CSB-CTRTI, Ranchi.

The benefits of employing a drone for pests and disease control are that it may be completed quickly without harming the crop or the soil [5]. Drones may also easily change the spraying height above the plants and travel swiftly over field crops [6]. Utilizing drone technology to improve the monitoring and administration of silk production operations is known as drone optimization. Drones can optimize several agricultural processes, such as precision agriculture, crop monitoring, pest management, and soil analysis [7,8]. Farmers may make educated decisions using real-time data on crop health, biomass, and growth from drones with sophisticated sensors and imaging capabilities [9]. Furthermore, it has been demonstrated that combining artificial intelligence with drones increases the effectiveness of jobs like identifying bird nests in agricultural areas [10]. Various contexts, including traffic and environmental parameter monitoring, have investigated optimization methodologies for drone-based monitoring [11,12]. These studies highlight how crucial it is to consider drone capacities and limitations when creating optimization frameworks. Additionally, research on the financial viability of drone use in agricultural production has demonstrated that drone technology can be an affordable solution for enhancing agricultural operations. [13]. Although there are many advantages to using drones in agriculture, there are also drawbacks, including regulatory restrictions, especially in areas like Sub-Saharan Africa [14]. It is imperative to comprehend and tackle these obstacles to employ drones in agriculture. Furthermore, drone technology's adaptability to various agricultural and environmental domains is demonstrated by its usage in monitoring oil contamination in coastal settings and agricultural terraces [15,16].

This review aims to delve into the multifaceted impact of drone technology on the sericulture industry, particularly focusing on its potential economic benefits and influence on traditional methodologies. By examining farmers' perspectives on drone technology, including their perceptions of its efficiency and monitoring capabilities, the chapter seeks to gauge their readiness to embrace drones in silk production operations. Based on existing research on technology adoption and precision agriculture, this chapter aims to develop tailored strategies that facilitate the successful integration of drones into sericulture practices. Through a comprehensive understanding of the factors influencing farmers' opinions of drone technology, such as perceived benefits and technical features, the chapter aims to identify key drivers and barriers to adoption. By leveraging this knowledge, the goal is to craft effective methods that encourage the widespread acceptance and utilization of drones within the sericulture industry. Ultimately, the integration of drone technology holds the promise of enhancing sustainability, improving productivity, and bolstering the long-term economic viability of sericulture activities in the face of evolving agricultural challenges. The current state of sericulture reflects a dynamic landscape characterized by advancements, challenges, and opportunities for improvement. By addressing the existing hurdles through innovative technologies like drones, the sericulture industry can overcome obstacles, enhance efficiency, and foster sustainable growth in silk production. The integration of drone technology in Indian sericulture represents a promising achievement with vast potential for enhancing efficiency and driving positive outcomes in silk production [17]. In the context of avian ecology research in Indonesia, the utilization of drone technology has shown promising prospects for enhancing data collection and research capabilities. Similarly, in the field of cyber-physical satellite systems and aerial vehicle security threat detection, drones have demonstrated their potential to provide intelligent frameworks for enhanced surveillance and threat detection [18,19].

2. Classification of Drones with Their Specifications

There are numerous varieties of drones, each with unique features and applications. Drones can be categorized according to their size, design, functionalities, and areas of use. Drones used for commercial, military, and recreational reasons include hexacopters, quadcopters, helicopters, micro-drones, and UAVs [20]. The technical parameters of these drones differ in terms of their capacity for carrying payloads, frequency of operation, autonomous degree, size, weight, type of rotor, speed, and other features [21]. Table 1 summarizes the various UAV model types used in recent decades. Scholars have utilized diverse methods to identify and categorize distinct drone kinds. Based on radar data, spectrograms, and cadence velocity diagrams, machine learning techniques and convolutional neural networks (CNNs) have been applied for drone-based identification and classification [22,23]. Based on their micro-Doppler signatures and Radar cross-section (RCS) properties, radar systems have been designed to differentiate between various drone types [24,25]. Furthermore, the unsupervised characterization of drone swarms has been proposed using machine learning techniques in conjunction with RF signals analysis [26]. Drones have also been used for purposes other than military and surveillance. They are increasingly being used in agriculture for tasks like pesticide spraying. [27]. The development of customized drone systems with GPS-equipped components for precise spraying applications has resulted from the use of drones in agriculture.

Table 1. Different types of drones with their specific functions in sericulture.

Type	Specific Function	Advantage	Disadvantage	Reference(s)
Fixed wing	It monitors the crops with such high precision and accuracy that it can easily protect against yield loss by detecting and identifying diseases in the field at a very initial stage.	Fly faster and longer distances	Reduce mapping efficiency, inflexible take-off and landing	[28]
Single rotor helicopter	Single-rotor drones are typically used for more specific tasks than fixed-wing drones. They are commonly used in agriculture for crop monitoring, scouting, and irrigation management.	Long endurance	The long, heavy spinning blades of a single rotor can be dangerous.	[29]
Quadcopter	These drones are designed for use in farming and agricultural applications. They range from small quadcopters to larger fixed-wing aircraft and are used to monitor crops, livestock, and land, providing valuable data for precision agriculture.	The simplest mechanical structure, the opposite force stays balanced	Light lifting capacity	[30]
Hexacopter	It has a variety of modes and exclusive functions for agriculture sprayer drones. It supports manual, semi-autonomous, and autonomous flight. It can monitor drug flow in real time and intelligently match the spray volume to achieve precise UAV pesticide spraying.	Greater redundancy	Insufficient performance and battery capacity	[31]
Octocopter	It allows farmers to monitor crop and livestock conditions from the air to monitor potential problems and help optimize field management.	Greater redundancy and lifting capacity	Several components to keep track of	[32]

UAVs are flying radio-controlled vehicles. The multi-rotor models are the only UAVs that can be further classified based on how many rotors are on its platform. Fixed-wing UAVs have a very different design than multirotor aircraft, and they are easier to fly due to the two aerodynamic structures. Fixed-wing UAVs normally have longer flight endurance capabilities, while multi-rotors can provide a stable image capturing and easy vertical take-off and landing (Figure 2). Multirotor aircraft with four, six, or eight rotors are referred to as quadcopters, hexacopters, or octocopters. Multirotors are subdivided into single-rotor, quadcopter, hexacopter, and octocopter. With more power, the octocopter offers all the benefits of the hexacopter. Although these gadgets are not cheap, they typically yield the highest quality aerial imagery. These eight-motor drones also offer the same advantages as quadcopters and hexacopters. In sericultural operations, small drones, specifically hexacopters, are commonly used because they offer greater stability and longer battery life compared to other types. This makes them well-suited for covering larger areas in a single flight (Table 2).

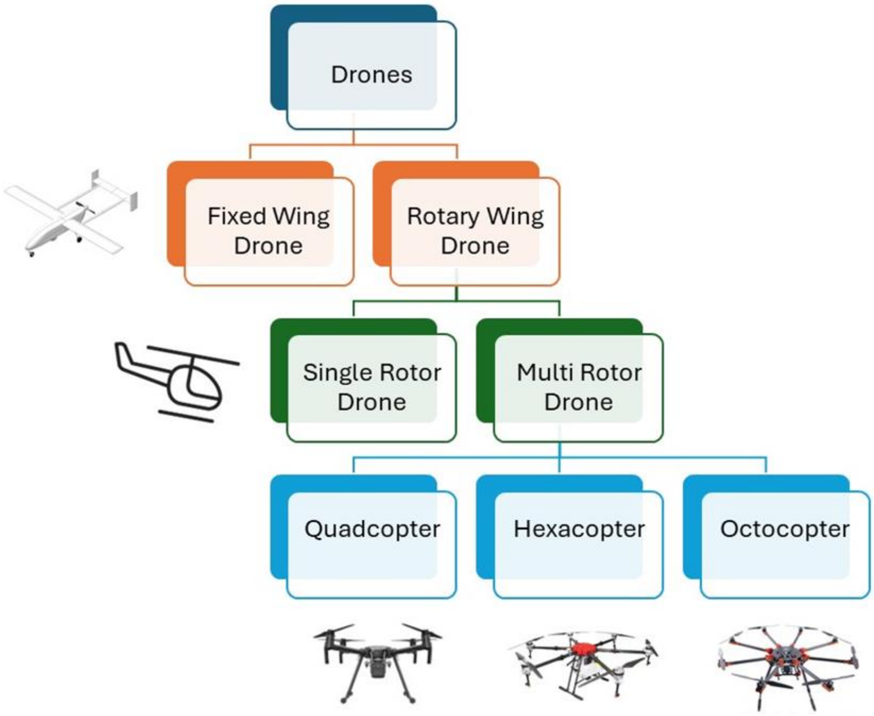


Figure 2. Different types of drones are used in sericulture.

Table 2. Classification based on all-up-weight including payload **(**adapted from [33]).

Category	Greater than	Less than or Equal to
Nano	0 Gms	250 Gms
Micro	250 Gms	2 Kgs
Small	2 Kgs	25 Kgs
Medium	25 Kgs	150 Kgs
Large	150 Kgs	No Limit (500 kg generally)

3. Crop Losses Due to Pests and Pathogens in Sericulture

There are serious issues affecting the production of agriculture. It is well-recognized that pathogens such as bacteria, viruses, fungi, and insect pests can seriously harm crops [34]. Estimates of the economic impact of losses are high, and they match with reported and professionally studied statistics [35]. In sericulture, the *Bombyx mori* nucleopolyhedrovirus (BmNPV) is a notable disease that poses a significant risk and can result in significant financial losses [36,37]. *Glyphodes pyloalis* Walker, a pest in the sericulture sector, significantly contributes to crop losses and damage [38,39]. Although pesticides are frequently employed in agriculture to prevent pests, they can paradoxically cause significant financial losses in sericulture [40]. Furthermore, pesticide use has been shown to decrease stress-responsive genes in insects, which may exacerbate the problem of pest resistance [40]. Moreover, studying host-pathogen interactions in sericulture is critical since silkworms, like *Bombyx mori*, have an innate immune system vital to their defense against pathogens [41]. According to estimates, for a variety of agricultural commodities, including wheat, maize, potatoes, rice, and soybeans, crop losses from pests can be significant, ranging from 17 to 30% [42]. Proactive pest management measures are crucial, as evidenced by the strategies recommended to reduce these losses, including the use of pest scouting data for damage prediction [43]. Furthermore, it has been projected that pests could cause major losses to the agricultural output of the planet, with weeds, animal pests, and pathogens together accounting for a large portion of these losses [44].

4. Conventional vs Drone-Based Spraying in the Tasar Host Plants

Comparing drone-based spraying to traditional knapsack spraying, notable gains in plant growth and yield characteristics have been shown [45]. This suggests that drones can effectively improve agricultural results. Furthermore, studies have demonstrated the benefits of drone-based spraying over conventional ground-based techniques by demonstrating the efficacy of UAVs in pesticide application for crop protection. An alternative to traditional pesticides is the application of RNA-based products for plant protection, as covered in studies by Cagliari et al. (2019) and Werner et al. (2020) [46,47]. This novel strategy could completely change agricultural pest and disease management. In addition, a brand-new spraying technique that uses an electrostatic spraying apparatus has been unveiled, providing benefits over traditional sprayers like less chemical usage and improved disinfection [48]. Compared to conventional tractor-mounted sprayers, drone-based pesticide applications usually use smaller spray volumes, resulting in more effective and focused spraying [49]. Further highlighting the advantages of sophisticated spraying techniques, real-time precision spraying systems have demonstrated notable cost savings compared to traditional approaches [50]. The droplet size using a Knapsack sprayer is >1000 µm, but the droplet size of a flat fan nozzle used in a drone is 200–250 µm, which saves resources and precisely uses resources such as nutrients, fertilizer, and pesticides. Figure 3 showcases the innovative use of a hexacopter drone for lime and bleaching powder spraying in Arjun and Asan fields, as demonstrated at CSB-CTRTI in Ranchi, India. This demonstration highlights the potential of drone technology in agricultural practices, particularly in enhancing precision and efficiency in crop management. Furthermore, Table 3 comprehensively compares conventional spraying methods and drone-based pesticide applications. This comparison underscores the potential advantages of drone technology in terms of precision, efficacy, and resource optimization in agricultural practices.

Figure 3. Lime and bleaching powder spraying using a hexacopter drone in Arjun and Asan field demonstrated at CSB-CTRTI, Ranchi, India.

Table 3. Comparison between conventional spraying and drone-based spraying [Adapted from Standard Operating Protocols (SOPs) for drone-based pesticide application in rice].

Parameters	Conventional Spraying	Spraying by Drones
Working efficiency	Time-consuming, laborious, and varied efficiency depending on the skill of the operator.	Quick, easy, and highly efficient
Exposure to hazards	Hazard of pesticide contamination and exposure of the operator	No/minimal operational exposure. Safer to operate
Water use efficiency	More water consumption (500 L/ha)	Less water consumption (15–40 L/ha)
Precision of spraying	Only small areas can be covered	Precision spraying and uniform coverage
Time management	During sudden pest/disease outbreaks inefficient crop protection due to more spraying time	During pest disease outbreaks, larger areas can be covered within short span, leading to efficient crop protection
Limitations	Can be operated efficiently up to a certain height only	Adaptable to undulated terrain, steep slopes, wet muddy fields, and inaccessible heights such as tall trees (oil palm, coconut, etc.)
Economics	Low return on investment	Higher return on investment.

Furthermore, Table 4 delineates the contrasting parameters of traditional and drone-based spraying techniques, highlighting the transformative potential of drone technology in agricultural applications. This comparative analysis underscores the efficiency gains, precision, and resource optimization offered by drone-based spraying methods over traditional approaches.

Table 4. Traditional vs drone-based spraying parameters.

Type	Spray Volume (L/ha)	Nozzle Type	No of Nozzles	Tank Capacity (L)	Flight Height (m) above Crop Canopy	Flight Speed (m/s)	Spray Width (m)	Flight Capacity (ha/h)	Suitability	Reference
Drone	15–40	Flat fan	4	5–20	1.5–3.0	3–5	3–5	2.0	Small & large fields, field crops, fruit orchards, vegetables, flowers, plantation crops, specialty crops like tea and coffee raised on undulated and steep slopes	[51]
Knapsack sprayer	300–500	Flat fan/ Hollow cone	1	10–16	0.6–1.0	0.5–1.5	<0.5	0.12	Small field plots, field crops, and vegetable	[52]
Taiwan sprayer	300–500	Solid cone/ Hollow cone	1	20	0.6–1.0	0.5–1.5	<0.5	0.19	Small field plots, field crops	[51]
Tractor-mounted boom sprayer	300–500	Flat fan/ Hollow cone	24	400	0.45–0.75	0.83	12	2.08	Row field crops like cotton, maize, soybean, oilseeds etc	[13]
Tractor-mounted orchard sprayer	1000	Flat fan/ Hollow cone	10	1000	1.0–6.0	1.2	10	1.38	Fruit Orchards	[53]

5. Regulation of Drones: Autonomous vs Manual

Drones can be controlled in both manual and autonomous ways. For proper functioning, drones need to be GPS calibrated in the particular location where spraying would occur. After connecting the battery with a drone, it is connected to a remote control or transmitter through which operation can be done. Flying speed is generally kept at 3–5 m/s and wind speed should not be >5 m/s during drone operation to avoid spray drift. Spraying or spreading could be done 2–3 m above the crop canopy to maintain proper swath width. There are 10 SOPs published for major crops (7 SOPs by PJTSAU, Hyderabad, and 3 SOPs by TNAU, Coimbatore). Before spraying or spreading, SOP should be followed for proper action. Spraying or spreading depends on crop, nozzle, and other parameters. After feeding proper input (geo-fencing, flying altitude, flying speed, etc.), the drone could spray autonomously (Figure 4). If obstacles are present in the field, it is advised to fly the drone manually to avoid any damage.

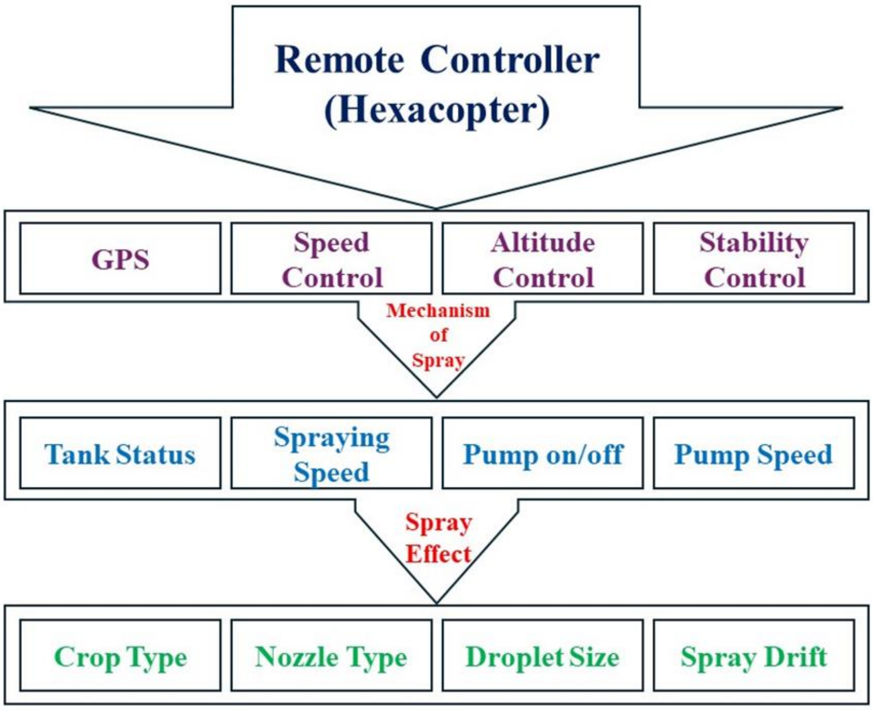


Figure 4. Different drone-based spraying mechanisms.

6. Effective Drone-Based Techniques for Managing Pests and Diseases in Sericulture

An inventive use of cutting-edge technology in silk farming is precision pest identification, which uses drones to enhance pest management techniques in agricultural environments. In precision farming applications, drones with imaging capabilities have proven useful in identifying illnesses, weeds, and pests [54]. According to Feng et al. (2022), UAV systems offer a novel pest monitoring and control approach in agricultural fields, supplying crucial data for informed decision-making [55]. According to research, using cutting-edge tools like drones to manage pests in agriculture precisely is important [56]. Optimizing pest management techniques in farming activities requires using digital tools for quick and precise pest detection [55]. Additionally, research suggests that using organic farming practices might improve pest management by increasing biodiversity, underscoring the benefits of incorporating natural pest control techniques into agricultural systems [57]. In addition, using drones to identify pests fits in with the larger trend of using technology in agriculture to improve productivity and sustainability [58]. Drone technology can help farmers spot pests more accurately, enabling them to implement more focused and effective pest management techniques. Drone technology has shown great promise in managing diseases and pests in a variety of fields, including sericulture. One novel method of managing pests in precision agriculture is the use of drones [56]. Drones are especially useful for applying pesticides in fields like sericulture because of their benefits, which include speed and the capacity to carry out activities without harming crops or soil [59]. Furthermore, standardizing and digitizing crop health data is essential for efficient monitoring when drones detect pests and diseases [60]. Drone-based scouting techniques have been demonstrated to enhance current Integrated Pest Management (IPM) strategies in the agricultural setting by offering insightful data for making decisions [61]. Moreover, using drones in agriculture offers significant financial benefits, indicating that drones can enhance pest and disease control practices. [62]. Drone use in orchard management has also been investigated, emphasizing the need to solve current deficiencies in methods for sensing and analyzing data for efficient pest control [32]. Further research has examined the incorporation of drones into environmental audits, providing insights into the perspectives of farmers and auditors on drone use for environmental monitoring [63]. This emphasizes how crucial stakeholder acceptability and participation are when using drone technology to manage pests and diseases in agricultural settings. Additionally, the potential of drones for conservation in protected regions highlights how adaptable they are in tackling a range of environmental issues [64]. The use of drone technology for disease and pest surveillance in the context of silkworm rearing can greatly enhance the production of mulberry silkworms. To monitor and scan for pests like Asian long-horned beetles, drones are used for precise pest control. This includes gathering pest specimens [56]. By offering useful data for decision-making, drone-based scouting techniques supplement integrated pest management systems [61]. Drones are considered efficient in agriculture, highlighting their potential to enhance farming methods. By leveraging AI for tasks such as weather forecasting, weed detection, pesticide application optimization, and animal health monitoring, drones can significantly improve agricultural production efficiency and reduce costs [13]. Furthermore, swarm intelligence for agri-food operations and support for food security initiatives are provided by the combination of drone technology and artificial intelligence, which holds promise for smart farming applications [65]. One useful application in modern agriculture is using drones to spray pesticides, demonstrating the adaptability of drone systems in carrying out many agricultural activities[27]. Throughout time, the idea of IPM has changed, embracing new technologies like drones to improve the efficacy of its pest management approaches.

Research shows that integrating drones into Integrated Pest Management (IPM) programs can lead to reduced pesticide use, safer handling practices, and more effective pest control outcomes [66]. Furthermore, it has been acknowledged that the application of drones in agriculture, particularly sericulture, has the potential to completely transform methods for managing and monitoring pests [60]. Incorporating IPM with drones into sericulture can enhance sustainable agricultural practices by safeguarding the long-term sustainability of silk production systems, fostering biodiversity, and lowering environmental impact. By implementing IPM strategies supported by drone technology, sericulture farmers can balance pest control and environmental conservation, ultimately leading to more resilient and sustainable silk production systems [67]. Figure 5 illustrates the extent of leaf gall infestation observed in Arjun plants under cultivation at CSB-CTRTI in Ranchi, emphasizing the importance of pest management strategies in maintaining crop health. This visual representation underscores the significance of research and interventions aimed at mitigating the impact of pests on agricultural yields. By utilizing drone technology equipped with multispectral cameras, real-time data on pest infestations can be gathered, facilitating timely interventions that adhere to IPM principles [68]. The use of low-cost live insect scouting drones like the ‘iDrone Bee’ can reduce human intervention efforts while capturing live insects in agricultural fields, benefiting the IPM community [61]. Additionally, using drones in intelligent sericultural pest management systems can provide targeted interventions through early pest detection and automated pesticide application, aligning with IPM principles [69].

Figure 5. Leaf gall infestation in Arjun plants maintained at CSB-CTRTI, Ranchi, India.

7. Smart Fertilization Systems in Sericulture Using Drones

The integration of drone technology has brought about significant advancements in sericulture, particularly in the development of smart fertilizing systems. Drones are used to evaluate the effects of pesticides and fertilizers, forecast fertilization requirements, and track agricultural performance [70]. The benefits of these systems include effective fertilizer spraying to lower labor costs and increase efficacy [71]. Drones are also essential for real-time data collecting, precision agriculture in smart farming methods, animal surveillance, fertilization, pesticide spraying, soil sampling, and other tasks. Drones are used in agriculture for more than only fertilizing; they are also used for field mapping, weather monitoring, and irrigation control [72]. To maintain production levels in the context of sericulture, where soil fertility is critical, consideration of nutrient management strategies is essential [73]. In addition, incorporating drone technology into smart farming models has made it possible to apply fertilizer and pesticides efficiently, which has enhanced agricultural practices [74]. Drones have become increasingly essential in modern sericulture due to their ability to carry various sensors and imaging technologies that provide valuable data for farmers. These sensors include RGB cameras, which capture high-resolution images of crops, offering insights into crop health, growth rates, and potential issues like insect infestations [75]. Additionally, drones equipped with multi-spectral sensors, thermal sensors, and cameras play a crucial role in precision sericulture by enabling in-depth field monitoring, mapping, and the detection of pests and water shortages [10]. Notwithstanding, the clear advantages of drone technology for smart farming, there are still obstacles to overcome, such as laws governing drone operations in cities [76]. Furthermore, worries about how drone exposure to pesticides affects the environment and how that affects reproduction emphasize the need for ethical study and innovation in smart farming techniques [77,78]. Efforts are being made to address security and privacy issues associated with the pervasive use of drones in smart cities [79]. According to a study of comparative analysis of different sprayers, work efficiency for drone sprayers was better than other sprayers [80] (Table 5).

Table 5. Economics of spraying (Knapsack sprayer vs Drone based sprayer).

Equipment	Tank Capacity (L)	Time (h)	Labour Requirement (Person/Day)	Work Efficiency (WE)
Knapsack sprayer	20	8	4	0.125
Boom sprayer	200	2	1 bullock pair, 2 person	0.50
Drone sprayer	10	0.33	2	3.03

An experiment was conducted with pesticide spray on rice to study the incremental cost and returns of drones compared with conventional knapsack sprayers [80]. Overall, the incremental benefit-cost ratio was found 1:3.09 and

1:7.03 for the Knapsack sprayer and drone, respectively, which suggests a cost saving by drone technology when compared with knapsack spray (1:3.09) (Table 6).

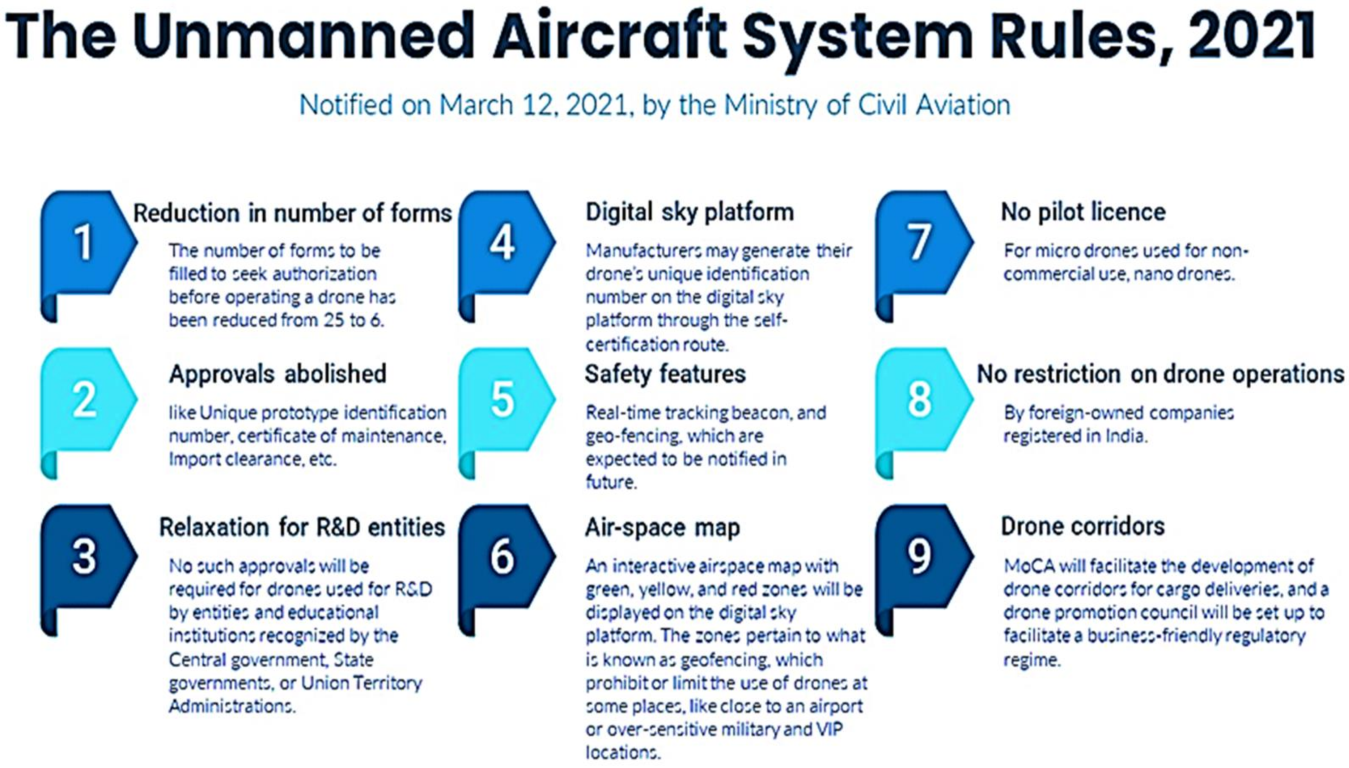
Table 6. Comparative economics of different sprayers for their incremental cost-benefit ratio.

Equipment	Incremental Yield over Control (q/ha)	Incremental Returns over Control (Rs/ha)	Incremental Cost of Cultivation (Rs/ha)	Incremental Cost-Benefit Ratio
Knapsack sprayer at 1X	9.50	17,746	5750	1:3.09
Drone spray at 1X dose (7000 kg/ha)	21.60	40,396	5750	1:7.03
Untreated control	0.00	-	-	-

8. Management and Regulation of Drone Operations

Laws related to drones in India have changed dramatically in the last few years. On 1 December 2018, Drone Regulations 1.0 went into effect, intending to increase the nation's potential for commerce and agriculture [81]. The usage of drones in a variety of industries, including urban planning, agriculture, and disaster management, has been made possible by these restrictions (Figure 6). It is crucial to remember that India currently prohibits using drones for commercial purposes [82]. Drones were used in India during the COVID-19 pandemic to monitor physical separation during lockdowns and to carry out containment measures [83]. An important factor to consider when assessing the efficacy and ramifications of drone laws is how these actions would affect the general welfare of the population. Research has been done to evaluate drone laws in India against global norms through comparative analyses [84]. These comparisons have concentrated on privacy, safety, and security, showing areas where Indian rules follow or depart from international norms. Gaining an understanding of these parallels will help India identify areas in which its drone regulations may need to be further improved to comply with international norms and promote innovation in the drone sector. Furthermore, research has examined the extent to which drones can be used for disaster relief in India as opposed to the United States, considering governmental and economic constraints [85].

Such studies might provide valuable insights into the future growth of the drone industry in India and its applications in crucial areas like disaster response and management. To get the pilot license, D2 (As there are 6 different types of forms from D1 to D6 for various purposes) form should be filled out and submitted to any DGCA (Directorate General of Civil Aviation)-registered RPTO. DGCA regulates rules developed by MoCa (Ministry of Civil Aviation) in India. The Indian airspace for drones is divided into Green, Yellow, and Red zones. The green zone is the airspace up to a vertical distance of 400 feet, not designated as a red or yellow zone. No permission is needed to fly in this zone. Yellow Zone is the airspace above 400 feet in the green zone and 200 feet within 8 to 12 km from an airport. It is a restricted zone where drone operations need a permit. Red Zones fall under Airport premises and Restricted areas where drone operation is prohibited. Before flying the drones, it must be assured that the field belongs to the green zone. If the spraying field is in the yellow zone, flying permission should be taken from the local SP; if it is in the red zone, then permission should be taken from ATC (Air Traffic Control). For example, in Indonesia, legal loopholes related to civil rights in drone usage emphasize the importance of establishing a robust regulatory framework tailored to the specific needs of the technology [86]. Such gaps can hinder the widespread adoption of drones in sectors like sericulture, where precise and efficient drone operations are essential. Studies focusing on managing and regulating drone operations highlight the necessity of clear guidelines and rules to ensure the safety and security of individuals, property, and the environment [76]. These regulations directly impact drone adoption in sericulture by providing a structured framework for integrating drones into agricultural practices while mitigating potential risks and ensuring compliance with legal requirements. Furthermore, the development of regulatory frameworks in countries like South Africa reflects a proactive approach to managing the growth of drone technologies [87]. By addressing risks associated with drone usage and establishing regulatory standards, these frameworks facilitate the adoption of drones in sectors like sericulture by fostering a conducive environment for innovation and technological advancement. In the agricultural context, exploring the challenges posed by regulations in Sub-Saharan Africa sheds light on the complexities involved in aligning regulatory practices with the needs of specific industries [14].



The Unmanned Aircraft System Rules, 2021

Notified on March 12, 2021, by the Ministry of Civil Aviation

1 **Reduction in number of forms**
The number of forms to be filled to seek authorization before operating a drone has been reduced from 25 to 6.

2 **Approvals abolished**
like Unique prototype identification number, certificate of maintenance, Import clearance, etc.

3 **Relaxation for R&D entities**
No such approvals will be required for drones used for R&D by entities and educational institutions recognized by the Central government, State governments, or Union Territory Administrations.

4 **Digital sky platform**
Manufacturers may generate their drone's unique identification number on the digital sky platform through the self-certification route.

5 **Safety features**
Real-time tracking beacon, and geo-fencing, which are expected to be notified in future.

6 **Air-space map**
An interactive airspace map with green, yellow, and red zones will be displayed on the digital sky platform. The zones pertain to what is known as geofencing, which prohibit or limit the use of drones at some places, like close to an airport or over-sensitive military and VIP locations.

7 **No pilot licence**
For micro drones used for non-commercial use, nano drones.

8 **No restriction on drone operations**
By foreign-owned companies registered in India.

9 **Drone corridors**
MoCA will facilitate the development of drone corridors for cargo deliveries, and a drone promotion council will be set up to facilitate a business-friendly regulatory regime.

Figure 6. Key highlights of the recent drone rules in India.

9. Recent Trends and Challenges Associated with Sericultural Activities

There have been encouraging developments and difficulties in the recent trends of drone use in sericulture. Because drones can increase productivity and efficiency in agriculture, particularly sericulture, more and more uses for them are being investigated. Research has demonstrated the advantages of deploying drones to oversee and control sericulture operations, including pest identification, irrigation control, and crop health evaluation [88]. Because these technologies offer real-time data and insights for well-informed decision-making, they have the potential to transform conventional sericulture techniques. Nonetheless, there are drawbacks to using drone technology in sericulture. Concerns about privacy and security are major issues when using drones, especially regarding data transmission and collection. Drones, constrained by energy, volume, and weight limitations, often rely on lightweight communication and security solutions. Ensuring secure drone networks resilient to interceptions and intrusions is paramount, highlighting the importance of addressing safety, security, and privacy issues related to drones and the Internet of Drones (IoD) [89]. To maintain compliance with current laws and rules, drone integration into sericulture operations may also need to address regulatory and ethical issues [90]. To maximize logistics and reduce interruptions, it is also important to thoroughly assess the dependability and effectiveness of drone delivery services for transporting materials connected to sericulture, such as mulberry leaves or silkworm eggs [91]. Additionally, for drones to be effectively used in sericulture, it may be necessary to overcome technological challenges, such as developing reliable systems for detecting and recognizing drones to prevent illegal drone activity that could disrupt sericulture operations. [92]. For sericulture stakeholders to effectively use drone technology, training programs, and capacity development measures may be necessary to ensure the seamless integration of drones into current sericulture practices and workflows [93]. The advantages of employing drones in sericulture span across social, economic, and environmental spheres, yet a prominent drawback remains the absence of SOPs tailored specifically for sericultural crops. This deficiency poses a significant challenge to maximizing the potential benefits of drone technology in silk production. It warrants the development of comprehensive guidelines to ensure its effective and safe utilization in the industry. SOPs for sericultural host plants need to be developed through research and developmental activities. Only then can entrepreneurs adopt drone technology in their field easily. Furthermore, the integration of IoT technology in sericulture, as demonstrated in a study by a team of researchers in 2023, has led to the development of smart sericulture systems. These systems leverage IoT to mitigate risks such as fire outbreaks, predator threats, and disease spread, thereby safeguarding silk production and farmers' financial resources. Moreover, advancements in drone technology have enabled the implementation of AI-equipped drones for optimizing agricultural productivity, as highlighted by [94].

10. Conclusions

Drone integration in sericulture is a promising and progressive development with the potential to transform the sector completely. Drone use in sericulture presents chances to improve silk efficiency of production, sustainability, and productivity while also aligning with more general sustainable development goals. Using multispectral cameras, diseases, and pests could be monitored easily through drones. Using drone technology in sericulture can improve rural development, economic growth, and living standards for those who work in the industry. It is critical to address issues and moral dilemmas around the use of drones as they continue to develop. Artificial intelligence developments also expand drone capabilities, allowing for automated inspections and better results across a range of applications. Sericulture stakeholders may propel the growth and development of the industry and create a more sustainable and efficient future by utilizing drones.

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Author Contributions

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Ethics Statement

Declared none.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All the authors have read and approved the final version of the manuscript.

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