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From Backpacks to Blades: A New Era of Pesticide Spraying

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Abstract

The agricultural sector is undergoing a significant transformation, driven by the imperative to enhance efficiency, optimize resource utilization, and minimize environmental impact. Pesticide application, a critical component of crop protection and yield optimization, is at the forefront of this evolution. This study provides a comprehensive, data-driven comparison of traditional pesticide spraying methods (ground-based and aerial) against emerging drone-based applications. This study indicates that while traditional methods offer lower upfront equipment costs and established operational familiarity, they are associated with higher long-term expenses due to labour intensity, chemical wastage, and significant environmental and safety liabilities. In contrast, drone spraying, despite higher initial investment, offers substantial long-term financial savings through reduced labour and chemical consumption, alongside considerable environmental and safety benefits.

Keywords: Efficiency; Optimize Resource Utilization; Environmental Impact; Drones

Introduction

The drone technology reveals that the cost-effectiveness of drone ownership is highly dependent on the scale of operation, with specific acreage thresholds determining profitability for farmers and custom operators. Furthermore, the complex regulatory landscape for drones, while a barrier, also fosters a specialized service industry. As technology advances, with hardware costs decreasing and battery life improving, drone spraying is poised to become increasingly accessible and economically viable, fundamentally reshaping agricultural practices towards greater precision and sustainability. S. S. Chouhan et al., 2025, Kar and Dal 2025 and N. Panotra et al., 2025 elaborated the use of drones in the modern agricultural practices.

Technology benefit towards environment

The environmental implications of traditional pesticide spraying are extensive and represent significant long-term costs. Conventional methods often involve broad application across entire fields, leading to considerable chemical waste and off-target drift. Pesticide drift, where chemical particles are carried by wind to unintended areas, contaminates the air and poses threats to wildlife. The severity of this drift is influenced by weather conditions, including wind velocity, temperature, and relative humidity. Chemicals can also leach through soil, be carried by surface runoff, or be accidentally spilled, resulting in the contamination of rivers, lakes, and groundwater. Studies in the United States have detected pesticides in nearly all sampled streams and over 90 % of sampled wells. Furthermore, the reliance on heavy machinery in traditional spraying leads to soil compaction, negatively affecting long-term soil health, its ability to absorb water and nutrients, and overall crop productivity. Overuse of chemicals can also harm beneficial soil microorganisms and reduce biodiversity, further degrading soil quality.

Comparison of traditional methods to drone spraying

The broad-spectrum application characteristic of traditional methods also negatively impacts biodiversity, harming beneficial insects crucial for pollination, such as honeybees, as well as birds and other local flora and fauna. Moreover, widespread and non-targeted chemical application contributes to the development of pesticide resistance in pests, necessitating higher doses or the use of new, potentially more potent formulations, which in turn increases costs and environmental burden. These environmental consequences represent substantial, often hidden, long-term costs, including ecological damage, reduced land productivity, and potential regulatory penalties, which are crucial for a holistic comparison.

Cost of the drones

The initial capital outlay for agricultural spraying drones can be substantial, though prices have decreased notably since 2020. Entry-level agricultural drones typically range from $5,000 to $10,000. Mid-range systems with advanced features are priced between $10,000 and $25,000, while high-end commercial systems with autonomous capabilities can cost anywhere from $25,000 to $50,000. High-performance drones specifically designed for precision agriculture may range from $15,000 to over $50,000 per unit, depending on their sensor capabilities and durability for large-scale operations. For custom drone service providers, the overall "Drones & Setup" investment, including acquisition, calibration, and comprehensive warranty plans, can range from $30,000 to $100,000. Industry analysts project a continued decrease in hardware costs, with an expected reduction of 15-20 % by 2027, suggesting increasing accessibility in the near future.

Advantages of drone technology

Drone technology offers substantial environmental advantages, aligning with global sustainability objectives. Drones operate on rechargeable batteries, significantly reducing reliance on diesel-powered machinery and the associated fossil fuel consumption. An Australian study indicated a 90% reduction in fuel use for pesticide application when using drones compared to tractors. Unlike traditional planes used for aerial spraying, drones do not directly release emissions into the atmosphere, contributing to less air pollution. The reduced need for heavy machinery also prevents soil compaction, preserving the natural composition and structure of the soil. This lowers the risk of erosion and supports healthier, more resilient soil for long-term productivity. By minimizing chemical drift and runoff through targeted application, drones protect beneficial insects (such as pollinators), birds, and other local flora and fauna from harmful exposures. Precision farming also reduces the need for land clearing, further supporting biodiversity. Additionally, drones equipped with thermal cameras can identify dry spots in fields, allowing for precise irrigation and preventing overwatering, leading to improved water distribution and conservation. These advantages position drone technology as a powerful tool for environmental stewardship and for mitigating regulatory risks associated with environmental damage.

Table 1. Key Performance Metrics: Drone vs. Knapsack Spraying

Metric	Drone Spraying System	Knapsack Spraying System	Difference/Improvement
Average Application Rate (l/ha)	26.96	490.28	Drone uses 94.5% less water
Field Efficiency (%)	76.5 %	87.23 %	Knapsack slightly higher, but for much smaller coverage
Effective Field Capacity (ha/h)	4	0.082	Drone is ~48 times faster
Pesticide Utilization (%)	Up to 85%	Maximum 30%	Drone is 2.8x more effective in utilization

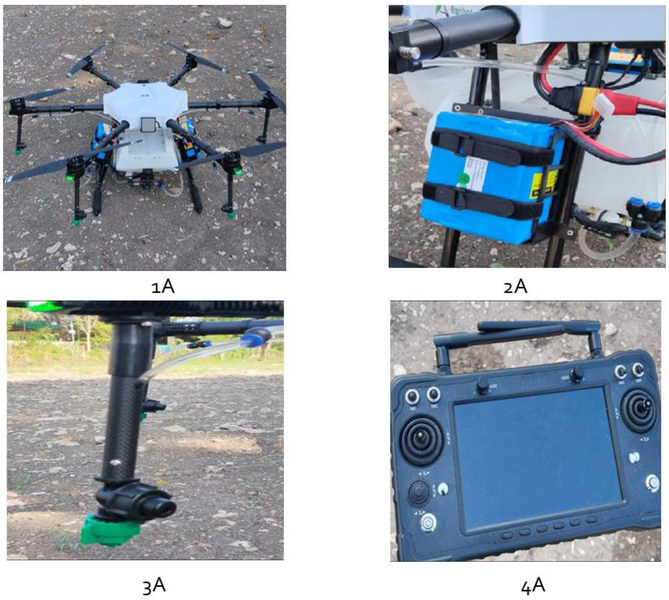

Fig. 1. 1A-Six-rotor agricultural spraying drone 2A- Battery set (Power source) 3A- Agricultural spraying nozzle 4A- Drone control unit (Remote controller) (Gadhe et al., 2025)

The above table shows the key performance metrics of Drone Spraying System versus Knapsack Spraying System. The Fig. 1. shows six rotor spraying drone along with battery set (Shown in Fig. 2.). The Fig. 3. is Agricultural Spraying nozzle along with Drone control unit (Fig. 4.). Gadhe et al. (2025) experimented Drone Spraying System in comparison with Knapsack Spraying System. The Drone Spraying System demonstrated an average application rate of 26.96 l/ha, with along with a field efficiency of 76.5 % and an effective field capacity of 4 ha/h. The Knapsack Spraying System demonstrated an average application rate of 490.28 l/ha, a field efficiency of 87.23 % with a benefit of significantly lower coverage rate, managing only 0.082 ha/h.

Safaeinejad M et al. (2025) studied the drone spraying vs. conventional spraying for reduced energy and environmental footprint in agriculture. The study revealed that conventional spraying techniques consume 2.43 times more energy than drone spraying. Specifically, conventional methods require 365.26 MJ/ha, while drone technology uses only 146.84 MJ/ha. The Global Warming Potential (GWP) associated with pesticide application is significantly higher for conventional methods, measuring at 41.284 kg CO_2/ha compared to just 14.485 kg CO_2/ha for drones.

Conventional farming methods relying on diesel fuel have significant environmental repercussions. The combustion of diesel not only contributes to greenhouse gas emissions but also leads to air pollution that can affect local ecosystems. The impact is particularly pronounced in intensive agricultural settings where machinery usage is high. While drones present a modern alternative, it is essential to consider their own environmental footprint. The production and charging of batteries used in drone technology are currently the largest contributors to their overall ecological impact.

Traditional Spraying Methods

Advantages

These methods generally require less specialized training, and farmers are often already equipped with the necessary machinery. They can also handle larger payloads, enabling coverage of extensive areas in a single session.

Disadvantages

Traditional methods tend to be less precise, leading to uneven application and potential overuse of chemicals. They can struggle in areas with uneven terrain, potentially requiring additional labour and time. This inefficiency can increase costs over time and contribute to chemical runoff. Furthermore, the reliance on heavy machinery can result in soil compaction, negatively impacting long-term soil health and crop productivity.

Spray Drones

Advantages

Drones offer high precision through GPS and sensors, leading to high efficiency and faster coverage. They significantly reduce labour costs and enable substantial chemical and water savings. Environmentally, they prevent soil compaction, reduce carbon emissions, and protect biodiversity. They also contribute to improved crop yields through targeted application.

Disadvantages

The initial investment for drones is high, and their operation requires technical knowledge and specialized training. Battery life can be a limiting factor for coverage per flight, and drones are subject to varying regulatory restrictions. There is also a risk of damage or loss to the equipment, and their payload capacity is generally limited compared to traditional machinery. This balanced overview of trade-offs enables farmers to make decisions based on their specific needs, farm size, and strategic priorities.

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