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Integrating precision technology in mechanized fertilizer sprayers: A step towards sustainable agriculture

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Abstract

India, with over 70% of its population directly or indirectly dependent on agriculture, continues to face significant challenges stemming from low productivity, traditional farming practices, and limited mechanization—particularly among small and marginal farmers. This research presents a novel approach to integrating precision technology into mechanized fertilizer sprayers to enhance operational efficiency, reduce labor demands, and minimize input wastage. The developed system incorporates an ergonomic, gear-driven manual propulsion mechanism coupled with a precision-controlled multi-nozzle boom for uniform chemical distribution. The design emphasizes affordability and adaptability for small landholdings, with the potential for future integration of GPS, Variable Rate Technology (VRT), and sensor-based automation.

Traditional methods such as backpack sprayers are labor-intensive, inefficient, and often result in uneven fertilizer and pesticide application—leading to poor crop performance and environmental risks. The proposed solution eliminates the need for manual pumping or fuel-powered operation, thus lowering operator fatigue and operational costs. The inclusion of adjustable nozzles and height-control mechanisms ensures uniform spraying, reduced chemical usage, and adaptability across diverse field conditions. This innovation bridges the gap between mechanical functionality and precision control, promoting sustainable agricultural practices and empowering grassroots farmers with accessible modern technology. It marks a significant advancement in precision agriculture, contributing to higher productivity, environmental sustainability, and economic viability.

Keywords: Precision agriculture, fertilizer sprayer, mechanized spraying, sustainable farming, smart farming equipment, input efficiency, small-scale farming, push-type sprayer, multi-nozzle system, agricultural mechanization

Introduction

Agriculture remains the backbone of the Indian economy, with approximately 73% of the population relying on it directly or indirectly for their livelihood. Despite this, farming practices in India continue to be dominated by traditional methods such as manual seed sowing, pesticide and fertilizer spraying, and harvesting, which are labor-intensive, time-consuming, and inefficient [Abayineh, A. (2016)]^[1]. As India faces the dual challenge of a growing population and limited agricultural productivity, the need for modernization in agricultural practices has become increasingly urgent [Issah (2018), Nangare (2014) & S. Chaudhari *et al* (2017)]^[12, 24, 5].

One of the critical areas requiring innovation is the method of spraying fertilizers and pesticides [Silas *et al* (2015)]^[32]. Conventional backpack sprayers demand considerable manual effort and result in uneven distribution of chemicals, leading to poor crop health, increased input wastage, and health hazards for the operator. This situation is further compounded by limited mechanization, insufficient power availability, and small landholdings, which restrict access to

advanced agricultural machinery.

In contrast, countries like Japan have demonstrated that even small farms can achieve high productivity through the adoption of compact, efficient, and time-saving mechanized tools [Anibude, E. C. (2016), Fox *et al* (2003)]^[3, 10]. Their success underscores the potential benefits of introducing modern equipment tailored to small and marginal farmers—who make up over 65% of the farming population in India [Johnson & Swetnam (2012)]^[14].

Precision agriculture technologies offer a transformative opportunity to improve chemical application practices [Kabse *et al* (2022), Kale *et al* (2015), Ghuge *et al* (2019)]^[16, 17, 11]. Mechanized sprayers integrated with precision controls, such as adjustable nozzles and wheel-powered pumping systems, can ensure uniform distribution, reduce input usage, and significantly lower operator fatigue [Jadhav & Sawale (2016), Taiwo & Oje (2008)]^[13, 33]. Additionally, these innovations support sustainable farming by minimizing environmental impact and improving crop yields fig.1.

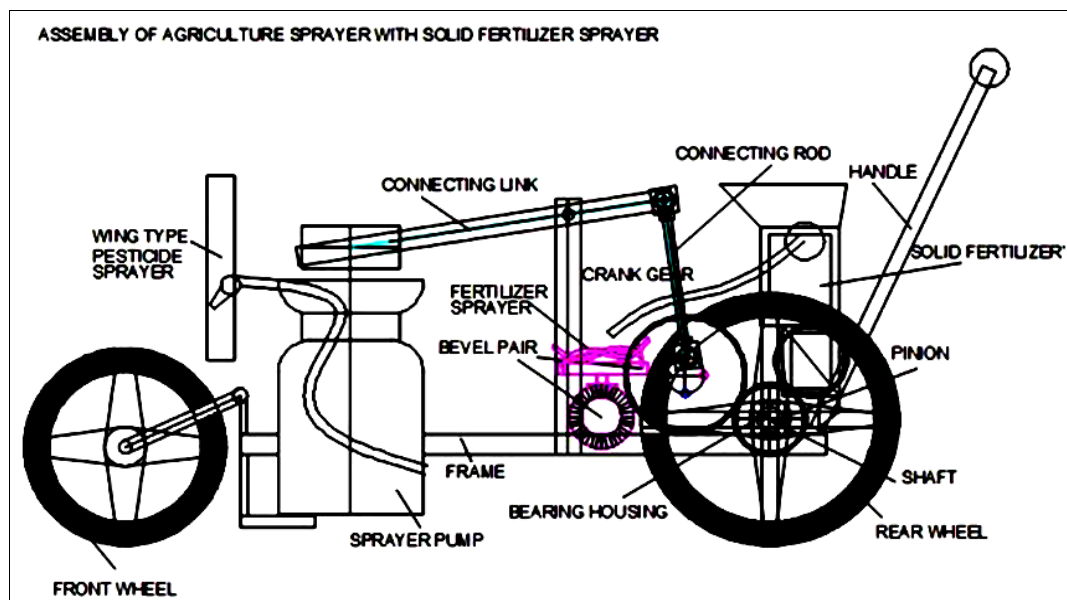


Fig 1: Model of sprayer and fertilizer (Ghuge *et al* (2019))^[11]

Given the importance of agriculture in both economic and social contexts, developing efficient, accessible, and affordable fertilizer and pesticide application machines is essential [Kulkarni *et al* (2015)]^[19]. By integrating precision technology into these systems, we can address longstanding issues in the sector, increase productivity, and contribute to a more sustainable agricultural future [Laukik *et al* (2013)]^[20].

Dileep *et al.* (2017)^[7] designed a pedal-operated, multipurpose bicycle-mounted sprayer system with an integrated water pump. This low-cost, portable solution utilized pedal energy for both locomotion and spraying simultaneously. While it proved useful in rural areas with limited access to power sources, the system's efficiency was constrained by its dependence on continuous pedalling for operation. The reciprocating pump mechanism was efficient in terms of basic energy conversion but lacked advanced automation and required constant manual input.

In similar developments, researchers have explored various combinations of mechanical components and local materials to build effective fertilizer sprayers. Common materials used include treated steel for the frame and shaft, plastic tanks and nozzles, and mild steel or round pipe for structural supports. However, these systems often lack integration with digital technologies, limiting their precision and adaptability across different field conditions. Investigated the limitations of chemical injection sprayers, particularly the time delays in concentrated pesticide dispersion. Their work emphasized the importance of localized injection systems at each nozzle to minimize delays and enhance uniformity. The solution involved reducing the diameter of fluid lines at spray boom tips, improving application precision—a fundamental principle in precision agriculture. The contributed to the development of autonomous robotic platforms capable of navigating through greenhouse environments to perform pesticide spraying tasks. These systems demonstrated successful implementation of automation, real-time navigation, and dose accuracy, significantly reducing manual labor and chemical waste.

The University of Nairobi developed a centrifugal, non-

positive displacement pump system designed for high-volume, low-pressure applications. Their model emphasized manual throttle control for dosage regulation, reinforcing the role of adjustable control mechanisms in effective chemical dispersion. These systems highlighted the advantages of chemical applications as alternatives to mechanical tillage and traditional labor.

Narode *et al.* created a manually operated three-wheeled fertilizer spreader, equipped with front-mounted impellers powered by gear-reduced centrifugal motion to ensure even fertilizer distribution. Likewise, Chaudhari *et al.* 2017^[29] proposed a solar-powered model consisting of a hopper, impeller disc, and frame-mounted drive system, contributing to renewable-powered fertilizer applications.

Akhil P.T. and team introduced a trolley-mounted fertilizer spreader, leveraging mechanical drive from the wheels through a gear train to the spreader disc. This approach significantly reduced human effort and fertilizer waste, improving both time efficiency and accuracy. Meanwhile, Hao Lvet *et al.* used 3D discrete element modelling to optimize an outer groove wheel fertilizer spreader, enabling better control over granular flow.

D.A. Mada *et al.* emphasized the need for a multifunctional, single-axle agricultural vehicle for both pre- and post-harvest activities. This aligns with the broader goal of mechanizing small farms without compromising affordability or functionality.

Methodology

The methodology adopted for this study involved the design, fabrication, testing, and performance evaluation of a mechanized fertilizer sprayer integrated with precision technology [Busari *et al* (2021), Miller *et al* (2001) & Mohite *et al* (2013)]^[4, 22, 23].

1. Design and Fabrication

- A conceptual model was developed to integrate traditional pedal or wheel-operated systems with modern technological enhancements such as variable rate control and digital sensors [Das (2015)]^[6] fig.2.



Fig 2: Lite-Trac (Das (2015))^[6]

- Components like a plastic tank, treated steel shaft, adjustable boom with four nozzles, crank mechanism, and a manually driven wheel system were selected (Kolhe *et al* (2014))^[18].
- The drive mechanism was designed with a gear ratio of 1:1.37, ensuring optimal stroke efficiency per linear distance covered [Shivaraja & Parameswaramurthy (2014), Busari *et al* (2021)]^[31, 4] fig.3.

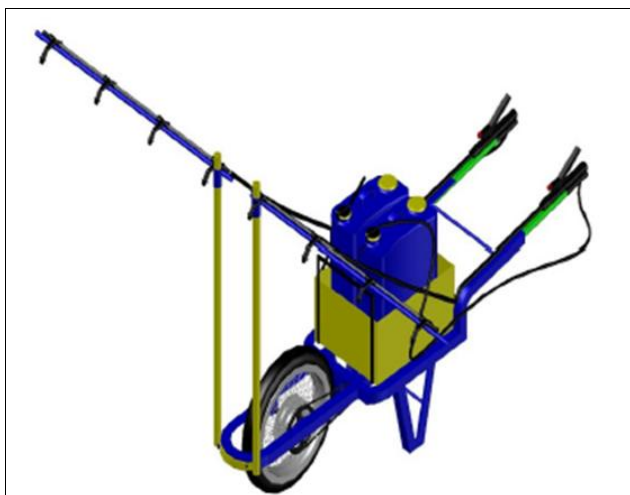


Fig 3: Designed hand-push type sprayer (Busari *et al* (2021))^[4]

2. Integration of Precision Technologies

- **Nozzle Control:** Precision nozzles were fitted to ensure uniform distribution, with adjustable flow based on crop type and growth stage [Deshpande *et al* (2018)]^[8].
- **Height & Width Adjustment:** The boom was designed with vertical and horizontal adjustment mechanisms to cater to different crop row configurations [Poudel *et al* (2017)]^[26].
- **GPS & VRT Integration** (future scope): A modular slot was integrated for potential GPS module installation and variable rate application controller.
- **Sensors:** Flow sensors and pressure gauges were provisioned to monitor and maintain consistent application rates.

3. Performance Testing

- The sprayer was tested across different soil and crop conditions to evaluate spray uniformity, coverage area, ease of operation, and fuel/power consumption [Narode *et al* 2015)]^[25].
- Manual pulling tests were conducted to measure efficiency in travel distance vs. spray output [Raut *et al* (2013)]^[28].
- Trials confirmed that the system provides a reliable and uniform spray with improved ergonomics compared to traditional backpack sprayers.

Results and Discussion

During the course of development, multiple iterations and performance tests were conducted to ensure the alignment of the sprayer's functionality with predefined objectives [Erdal Ozkan, H. (2015)]^[9]. A key metric assessed was the time and area covered during pesticide application. The introduction of multiple nozzles across an adjustable boom greatly enhanced spraying efficiency, enabling uniform coverage of larger areas in reduced time [Joshua *et al* (2010), Malonde *et al* (2016), Poratkar *et al* (2013), Kabse *et al* (2022)]^[15, 21, 27, 16] fig.4.

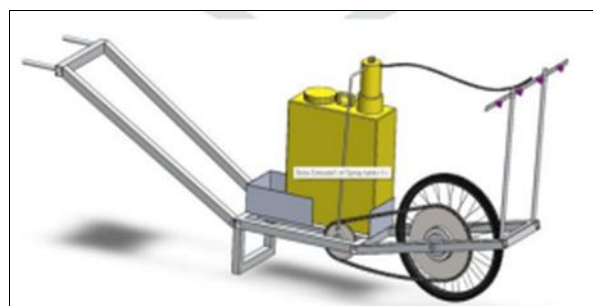


Fig 4: Design of Agricultural Sprayer (Kabs *et al* (2022))^[16]

The precision mechanism operates as the sprayer is manually pulled, with mechanical drive from the wheels converting motion through a gear train to power the pump. With a 457.2 mm diameter wheel connected to a 52-tooth drive gear and a 38-tooth driven gear (gear ratio 1:1.37), every 1436.33 mm of linear movement results in 1.37 pumping cycles. The piston pump, with a 50 mm diameter and 100 mm stroke length, ensures consistent pressure delivery to the accumulator.

The accumulator stores pressure and feeds it to a four-way splitter distributing fluid through polyurethane pipes to four strategically positioned spray nozzles on an adjustable boom. The boom, supported by rods and guide bushes, allows vertical and angular adjustments according to row spacing and crop height. These nozzles are precision-tipped for variable spray streams depending on the crop's needs [Sharma (2010)]^[30].

Incorporating Precision Agriculture Technology (PAT), the system can be further enhanced using:

- GPS-guided mapping for precise field boundary identification and path tracking.
- Variable Rate Technology (VRT) to adjust fertilizer or pesticide dosage based on soil and crop health data.
- IoT integration and real-time sensors to monitor flow rate, tank levels, and nozzle functionality.

- Mobile app connectivity for operators to control and monitor the application rate, area coverage, and maintenance schedules.

Conclusion

The integration of precision technology into mechanized fertilizer sprayers represents a significant advancement for Indian agriculture, especially in small and marginal farms. The developed model ensures efficient and uniform spraying while reducing human effort and chemical wastage. By leveraging GPS, variable rate technology, and sensor feedback, such systems can adapt to varying field conditions and crop requirements.

This step towards mechanization coupled with precision farming can bridge the gap between traditional practices and modern sustainable agriculture. The model, being affordable and scalable, offers immense potential to uplift rural farming efficiency and productivity in India. With future improvements in automation and smart farming integrations, the sprayer can further contribute to India's vision for smart and sustainable agriculture.

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