

## Original Research Article

# Drones vs. Tradition: Economic Efficiency and Challenges in Modern Agriculture through Machine Learning

### Abstract (Please see comments)

Indian agriculture, a cornerstone of the nation's economy, significantly contributes to GDP, provides employment to nearly half of the population, and ensures food security for over 1.4 billion people. However, the sector faces critical challenges, including declining productivity, limited mechanization, labour shortages, and the impacts of climate change. Traditional, labour-intensive farming methods often limit the scope for scaling agricultural practices, particularly in crops like paddy, which is a staple food for millions. In this context, drones—unmanned aerial vehicles (UAVs)—emerge as a promising technology capable of addressing these limitations. Drones are equipped with advanced sensors and imaging capabilities that allow them to collect real-time data on crop health, soil conditions, and pest infestations. This information empowers farmers to make data-driven decisions, optimizing inputs such as water, fertilizers, and pesticides. These efficiencies are crucial in a country like India, where smallholder farmers dominate the agricultural landscape and operate under tight economic constraints.

This study, conducted in Tamil Nadu with a focus on paddy cultivation, compares the outcomes of drone-assisted farming with conventional practices. The results reveal that drones can enhance economic efficiency by an impressive 90%. This efficiency gain is attributed to precise monitoring and targeted interventions, which reduce wastage of resources. For instance, drones can identify specific areas requiring attention, allowing farmers to apply inputs selectively rather than uniformly across fields. Another notable finding is the reduction in cultivation costs by approximately 30%. Conventional farming often involves significant labor and input costs, which are compounded by inefficiencies in application and management. Most importantly, the study highlights a substantial 41% increase in farmer income. This rise is driven by higher yields and better-quality produce, both of which result from timely interventions and optimal resource management. By ensuring healthier crops, drones reduce the likelihood of losses due to pests or diseases, thereby stabilizing and improving farm productivity. Despite the promising benefits, widespread adoption of drones in Indian agriculture faces challenges, including high initial costs, lack of technical expertise, and regulatory hurdles. Addressing these barriers through policy support, subsidies, and farmer training programs is essential to unlock the full potential of this technology.

Keywords: Drone Technology; Paddy cultivation; Constraints

## 1. INTRODUCTION (Please see comments)

Agriculture remains the backbone of India's economy, with nearly 47 percent of the population relying on it for their livelihood. As the world's most populous nation with over 1.42 billion people, ensuring food security through increased agricultural productivity is paramount. In conventional farming, pesticides and fertilizers play crucial roles in managing pests and promoting plant growth; however, their manual application often incurs high labour costs and significant health risks, including conditions like cancer, asthma, and other disorders due to chemical exposure. In recent years, advancements in drone technology—commonly referred to as unmanned aerial vehicles (UAVs)—have introduced a new era in agricultural practices, promising substantial cost reductions, enhanced efficiency, and improved crop yields. Drone technology has made transformative contributions across various industries, with agriculture experiencing some of the most significant impacts. Drones are reshaping traditional farming by enabling precision agriculture techniques that promote resource efficiency and environmental sustainability. By providing accurate data on crop health, soil conditions, and water needs, drones minimize the excessive use of fertilizers and pesticides, reducing environmental runoff and preserving water quality in nearby ecosystems. Additionally, drones support sustainable land management practices by monitoring conservation efforts, such as cover crop maintenance and soil erosion control.

Water management in agriculture has also been greatly enhanced by UAVs. Drones offer real-time data on soil moisture and crop water requirements, allowing farmers to apply water more precisely, which is critical for regions experiencing water scarcity. This precision irrigation helps conserve water and maintains agricultural productivity, supporting the economic stability of water-stressed regions (Evans et al., 2013). Through these capabilities, drones are not only helping to optimize resource use but also driving improvements in yields, time savings, and sustainable land management practices. The applications of drones in agriculture are wide-ranging. Remote sensing drones equipped with electromagnetic spectrum cameras gather precise data on soil and crop conditions, enabling the detection of nutrient deficiencies, pest damage, and crop health indicators. This data empowers farmers to make informed decisions, optimizing crop management practices. Drones also contribute to labor savings and efficiency in seed planting and crop spraying. With specialized containers, drones can plant seeds at a lower cost and with a higher success rate, as exemplified by a drone seeding initiative along the Pinakini River in India, which aimed to reforest 4,000 hectares. In crop spraying, drones utilize advanced technologies like TOF lasers and GNSS signals for accurate pesticide application, reducing environmental impact and minimizing human exposure to harmful chemicals. By reducing input costs and addressing labor shortages, drones bring significant economic advantages to the agricultural sector. Despite the potential of UAVs, challenges remain. Factors like pesticide drift due to wind and the high costs associated with drone acquisition and maintenance pose barriers, particularly for small and medium-sized farms. Additionally, specialized training and technical expertise are required for effective drone operation, which can limit

**Comment [P1]:**

- **Clarify traditional farming challenges:** Mention specific impacts of labor shortages and climate change on paddy farming.
- **Methodology:** Briefly outline how data was collected (e.g., yield measurements, cost comparisons).
- **Drone capabilities:** Specify the types of sensors or technologies used (e.g., multispectral imaging).
- **Scalability:** Discuss how drone adoption can be scaled across different regions or farm types.
- **Future research/policy:** Add a call to action for addressing adoption barriers, such as developing affordable drones or providing subsidies.
- **Conciseness:** Simplify long sentences for better clarity and readability.

adoption among smaller farmers, potentially exacerbating disparities within the sector. This study aims to fill the current research gap in understanding the economic impact of UAVs in agriculture. Although drones have seen increasing application, there is limited research on their economic benefits and challenges in farming. This study will examine the efficiency, profitability, and constraints in UAV adoption in agriculture, with a focus on UAV application in paddy cultivation. As artificial intelligence (AI) increasingly integrates with drone technology, the efficiency and precision of UAVs in agriculture are anticipated to grow, making them a vital tool for cost-effective and sustainable farming.

### Hypothesis

1. UAV technology significantly impacts farmers' income.
2. The use of drones in agriculture enhances farmers' efficiency.
3. Constraints in UAV technology contribute to disadoption.

### Objectives

1. To analyze the efficiency of UAVs compared to conventional methods in paddy cultivation.
2. To estimate the profitability and identify constraints in UAV adoption.

### 1. MATERIALS AND METHODS (Please see comments)

This study was conducted in Trichy and Pudukkottai districts of Tamil Nadu where multistage sampling technique is used. The sample size is 60 in unmanned aerial vehicles (UAV) using farmers and 100 farmers in conventional paddy cultivation.

#### Data Envelopment Analysis- Economic efficiency

The non-parametric linear model estimated by the Data Envelopment Analysis has been described for the first time in 1978 (Charnes *et al.*, 1978). The positive advantage of the DEA is due to an opportunity to arrange a hypothetical function of production made by a different combination of input and output hence, the distance from the frontier of this function is the index of technical inefficiency (Latruffe, 2010; Galluzzo, 2013; Charnes *et al.*, 1978; Battese, 1992; Coelli, 1996; Farrell, 1957). In fact, along this function there are all the possible combinations of inputs or output able to minimize costs or maximize the income. Roughly speaking, fluctuations in the model from the frontier of the function of production are inefficient and the technical efficiency is described as a set of opportunities for entrepreneurs in maximizing the output minimizing in the same time inputs or vice versa (Bojnec and Latruffe, 2008). In this research, the economic efficiency has been estimated by a non-parametric model using the DEAP.

#### Responses-Priority Index (RPI)

In the quantification of constraints expressed by the farmers, there was a problem, whether emphasis should be given for the number of responses to a particular priority or to the highest number of responses to a constraint in the first priority. But, both lead to different conclusions. To resolve this,

**Comment [P2]: • Contextualize the importance of paddy cultivation:** Begin by elaborating on the significance of paddy cultivation in India, especially in Tamil Nadu. You can provide statistics or examples highlighting its economic, cultural, and social importance.

- **Highlight the challenges of conventional farming:** Expand on the specific challenges faced by farmers, such as labor shortages, high costs of pesticides, and environmental degradation. Link these challenges directly to the need for innovative solutions like UAVs.
- **Discuss the role of AI in drone technology:** Since AI is integrated with UAV technology, discuss how AI algorithms enable precise data collection and resource management, improving efficiency.
- **Clarify the scope of your study:** While you mentioned Tamil Nadu, specifying why these districts were chosen (Trichy and Pudukkottai) can add depth to the introduction. Also, briefly introduce the sample size and methodology to provide readers with an understanding of the structure.

a Responses-Priority Index (RPI) was constructed as a product of Proportion of Responses (PR) and Priority Estimate (PE), where PR for the *i*th constraint gave the ratio of number of responses for a particular constraint to the total responses.

where, RPI = Response Priority Index for *i*th constraint

$$RPI = \sum_j X_{ij} / \sum_{i=1}^k \sum_{j=1}^k X_{ij}$$

Where,

RPI<sub>*i*</sub> = Response priority index for *i*th constraint,

*f<sub>ij</sub>* = Number of responses for the *j*th priority of the *i*th constraint (*i* = 1, 2, ..., *l*; *j* = 1, 2, 3, ..., *k*), = Total number of responses for the *i*th constraint

*K* = Number of priorities (1- Strongly agree, 2-Agree, 3-Moderate, 4- Disagree, 5- Strongly disagree),

*X* [ (*k*+1) – *j* ] = Scores for the *j*th priority, = Total number of responses to all constraints

Here, larger the RPI, higher was the importance for that constraint

## 2. RESULTS AND DISCUSSION (Please see comments)

The input cost, operational cost and cultural practice are the major contributor of income difference. The economic efficiency of UAV technology is almost ninety per cent which is high when compare to conventional farmers. Training the farmers in using technology will increase their yield, income, profit.

UAV technology in agriculture help to increase their income by 41 per cent and reduce the cost of cultivation by 12 per cent. The profit earned from adoption of technology will increase the profit by Rs.4355/ac. UAV are more efficient (88 per cent) and they range between 75-100 per cent efficiency compared to conventional farmers (71 per cent). The profitability of UAV using farmers is high compared to Conventional farmers shown in Table 1.

Table 1. Cost and returns of UAV and conventional method of Paddy cultivation (in acre)

Method	Conventional	Drone
Total cost (Rupees)	27723.2	22857.5
Gross income (Rupees)	39100	40640
Net income (Rupees)	11376.8	17782.5
Yield(kg/ac) (Rs. 21/kg)	1920	1950

**Comment [P3]: • Clarify sampling method:** Explain in more detail how you selected farmers for both the UAV and conventional farming groups. This will help the reader understand if there were any biases in the selection.

**• Enhance the explanation of Data Envelopment Analysis (DEA):** The section on DEA can be further expanded to explain how it works in layman's terms for readers unfamiliar with it. Include a brief explanation of TE (technical efficiency), AE (allocative efficiency), and EE (economic efficiency), and how each relates to the overall assessment of farm performance.

**• Expand on RPI Methodology:** Consider breaking down the Responses-Priority Index (RPI) into clear, easy-to-understand steps. You might want to define what each score means in the context of your study and why the specific RPI formula was chosen.

**Comment [P4]: • Visual aids:**

Tables are a great way to present data, but figures and graphs (such as bar graphs for efficiency comparison, income increase, and yield differences) can provide clearer insights. Consider adding visuals to support your findings.

**• Discuss results in depth:** While you've provided important numerical data, explaining why UAVs yield higher economic efficiency (e.g., resource optimization, less pesticide wastage) could be elaborated further.

**• Address challenges more comprehensively:** While you briefly mentioned the challenges related to UAV adoption, delve deeper into why these issues persist and how they affect adoption rates. For instance, explain how smaller landholdings influence farmers' reluctance to invest in UAV technology.

**• Compare with other studies:** Where possible, compare your findings with similar studies in other regions or countries. This can strengthen your discussion and show the broader applicability of your findings.

The total cost incurred by Conventional farmers is more because of high input cost pesticides and labour. Drones offer a cost-effective alternative to traditional methods of crop monitoring and management. Conventional techniques, such as manual scouting and satellite imagery, are often labor-intensive, time-consuming, and expensive. In contrast, drones can cover large areas quickly and provide real-time data at a fraction of the cost. This reduction in labor requirements translates to significant savings for farmers, who can reallocate their resources to other critical aspects of their operations

Furthermore, drones can perform tasks that are hazardous or difficult for human workers, such as spraying pesticides in tall crops or rough terrain. By reducing the reliance on manual labor, drones help mitigate risks associated with farming and improve worker safety. The automation of these tasks also allows for more consistent and accurate application of agricultural inputs, further enhancing crop quality and yield.

**Table 2: Efficiency of UAV and conventional method of Paddy cultivation**

Categories\Efficiency	TE	AE	EE
Conventional method	98	67	65
UAV technology	95	93	88

**Table 3: Number of farmers under different frequency of efficiency**

Categories\Frequency	30-45	45-60	60-75	75-100
Conventional	10	28	19	23
UAV technology	0	0	3	77

The technical, allocative and Economic efficiency of drone farmers and conventional farmers is shown in the table 2. Economic efficiency of UAV technology farmers is 88 per cent shows they will get maximum level of output with given level of input and the efficiency of conventional is less i.e., 65per cent. The difference in efficiency is mainly due to optimum allocation of resources. Technical efficiency of Conventional is high shows they use more input to get maximum output, whereas the allocative efficiency is 67 per cent shows the cost is high incurred by conventional farmers is more to get profit. The frequency depicts a greater number of farmers who are UAV technology are 75-100 per cent efficient and there is absence of 30-60 per cent efficiency shows they are highly efficient as shown in table 3.

**Table 4: Reasons for non-adoption of UAV technology**

SI. No	Adoption	RPI	Rank
1	<b>Land size (small and marginal farmers)</b>	<b>0.875</b>	<b>1</b>
2	Lack of UAV vehicle	0.729	2
3	Costlier than conventional	0.697	3
4	Past negative experience	0.512	4
5	Labour availability in few places	0.310	5

The results of RPI index for reasons for non-adopting UAV technologies are listed in table 4.

The adoption of UAV (drone) technology in agriculture is influenced by several key factors, with the most significant being the size of landholdings among small and marginal farmers, which has a high Relative Priority Index (RPI) of 0.875. This indicates that farmers with limited land are particularly cautious about investing in UAVs. The next major factor is the lack of availability of UAVs, with an RPI of 0.729, suggesting that limited access to these vehicles poses a considerable barrier. Cost concerns follow closely, as many farmers perceive UAVs to be costlier than traditional methods, reflected by an RPI of 0.697. Past negative experiences, with an RPI of 0.512, also deter adoption, as farmers who have previously encountered issues with UAV technology are less inclined to reinvest. Lastly, labor availability in some areas has a lower influence, with an RPI of 0.310, indicating that labor shortages may not be a primary driver for adopting UAVs. Together, these factors highlight the importance of targeted strategies to improve accessibility, affordability, and reliability of UAV technology to encourage its adoption.

**Table 5: Constrains faced by drone lenders**

SI. No	Adoption	RPI	Rank
1	<b>Transport Vehicle</b>	<b>0.726</b>	<b>1</b>
2	Lack of Fund	0.637	2
3	Lack of trained Pilot	0.425	3
4	Farmers Dis-adoption	0.409	4
5	Maintenance problem (accidental Damage and Battery Charging)	0.358	5

Drone lenders face several constraints that affect their operations and adoption rates shown in table 5. The most significant challenge is the reliance on transport vehicles, which ranks first with a Relative Performance Indicator (RPI) of 0.726, emphasizing the importance of reliable logistics. Financial constraints emerge as the second most pressing issue, with an RPI of 0.637, indicating a lack of funds for both acquisition and maintenance of drones. Additionally, the shortage of trained pilots ranks third with an RPI of 0.425, highlighting the need for skilled operators to effectively utilize the technology. Farmers' disadoption of drone services is also a concern, holding the fourth rank with an RPI of 0.409, suggesting reluctance or difficulties in integrating these services into their practices. Finally, maintenance problems, including accidental damage and battery charging, rank fifth with an

RPI of 0.358, underscoring operational challenges that further complicate the effective use of drones in agriculture.

### 3. CONCLUSION (Please see comments)

This study aims to explore the economic dynamics of drone use in agriculture, addressing the lack of previous research and the growing integration of AI in farming. It focuses on paddy cultivation in Tamil Nadu's Thanjavur and Madurai districts, with a sample size of 60 for UAV technology and 80 for conventional methods. The major contributors to income differences are input and operational costs. Farmers using UAVs achieve nearly 90% economic efficiency, significantly higher than conventional farmers. UAV technology increases income by 41% (Rs. 14,750/ac for UAV vs. Rs. 10,400/ac for conventional) and reduces cultivation costs by 30% (Rs. 26,190/ac for UAV vs. Rs. 29,900/ac for conventional) due to lower pesticide costs. UAVs are more efficient, with an 88% efficiency rate compared to 65 per cent for conventional methods. This study fills the research gap by highlighting how UAVs reduce costs, save labor, and improve efficiency, emphasizing their crucial role in modernizing and sustaining agricultural practices with AI integration.

#### Implication and Impacts

To maximize the benefits and mitigate the challenges associated with drone use in agriculture, several strategies can be implemented. Developing standardized guidelines for pesticide application using drones is crucial to ensure consistent and safe practices. Regulatory bodies and agricultural organizations should collaborate to establish protocols that minimize the risk of pesticide drift and ensure the appropriate dosage is applied to crops. Additionally, advancements in drone technology, such as improved stability and precision in varying weather conditions, can help address the issue of drift and enhance the accuracy of input application.

To address the high initial investment barrier, governments and agricultural organizations can provide subsidies or financial assistance programs to support small and medium-sized farms in adopting drone technology. This support can help level the playing field and ensure that the benefits of drones are accessible to a broader range of farmers. Furthermore, the development of cost-effective, user-friendly drones and software tailored to the needs of smaller farms can also contribute to wider adoption. Training programs and extension services should be made available to farmers to equip them with the necessary skills to operate drones effectively and interpret the data collected. By addressing these challenges, the agricultural sector can fully harness the potential of drone technology to enhance productivity, sustainability, and economic viability.

### 4. REFERENCES (Please see comments)

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**Comment [P5]:** • **Reaffirm the importance of UAV technology:** Re-emphasize the economic and environmental advantages that UAV technology offers to Indian farmers, especially in terms of reducing costs and enhancing efficiency.  
• **Discuss implications for policy and practice:** Expand on the implications for government policies. Specifically, discuss potential subsidies, training programs, or partnerships with drone manufacturers that could help small farmers.  
• **Suggest further research:** Mention areas that require more investigation, such as long-term impacts of UAV technology on soil health, yield quality, or its economic viability for small farmers in other regions.

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**Comment [P6]: • Consistency in formatting:** Ensure that all references follow a consistent citation style (e.g., APA, MLA). You may need to adjust the formatting of author names, publication years, and titles.

• **More recent references:** Try to include some more recent studies (especially from 2020 onwards) on drone use in agriculture, AI integration, or economic impact assessments. This can make your paper more current and relevant.

• **Cross-check references for relevance:** Ensure that all references are directly relevant to your research topic. For example, studies that address drone use in paddy cultivation specifically will be more helpful than generic drone research.

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