Original Research Article

Advancing Paddy Cultivation: Assessing Economic Efficiency and Constraints of Drone Technology in Indian Agriculture

Abstract

Indian agriculture, the backbone of the nation's economy, contributes significantly to GDP, provides employment to nearly half the population, and ensures food security for over 1.4 billion people. However, the sector faces challenges like declining productivity, limited mechanization, labor shortages, and climate change impacts. Traditional farming methods, particularly in paddy cultivation, often hinder scalability and efficiency. Drones, or unmanned aerial vehicles (UAVs), offer a transformative solution. Equipped with advanced sensors and imaging capabilities, drones provide real-time data on crop health, soil conditions, and pest infestations. This enables farmers to make precise, data-driven decisions, optimizing inputs like water, fertilizers, and pesticides. Such efficiencies are crucial for India's smallholder farmers, who operate under tight economic constraints. A study in Tamil Nadu focusing on paddy farming revealed that drone-assisted agriculture improves economic efficiency by 90%. This is achieved through precise monitoring and targeted interventions, reducing resource wastage. For example, drones pinpoint specific areas needing attention, allowing selective application of inputs instead of uniform distribution. Cultivation costs decrease by approximately 30%, thanks to reduced labor and input inefficiencies. Most importantly, the study found a 41% increase in farmer income, driven by higher yields and better-quality produce. Timely interventions and optimal resource management ensure healthier crops, minimizing losses from pests and diseases and enhancing farm productivity. Despite these benefits, drone adoption in Indian agriculture faces hurdles such as high initial costs, limited technical expertise, and regulatory challenges. Addressing these issues through subsidies, policy support, and farmer training programs is essential to maximize the technology's potential and promote sustainable agricultural practices. By leveraging drones, Indian agriculture can overcome critical challenges, ensuring improved productivity, profitability, and sustainability for farmers.

Keywords: Drone Technology; Paddy cultivation; Constraints

1. INTRODUCTION

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 (Time Of Flight) lasers and GNSS (Global Navigation Satellite System) 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 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

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 (Data Envelopment Analysis Program) software.

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, a Responses-Priority Index (RPI) was constructed as a product of Proportion of Responses (PR) and Priority Estimate (PE), where PR for the ith 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

$RPI = \Sigma_{j}= Xf_{ij\ [(k+1)-j]} / \Sigma_{i=1}\Sigma_{j=1}$

Where,

RPI_i = Response priority index for ith constraint,

f_{ij} = Number of responses for the jth priority of the ith constraint (i= 1, 2……, l; j= 1,2,3…..k), = Total number of responses for the ith constraint

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

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

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

2. RESULTS AND DISCUSSION

The input cost, operational cost and cultural practice are the major contributor of income difference. The economic efficiency of UAV technology is almost 90 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.4,355/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)

Cost and Returns/Methods	Conventional	Drone
Total cost (Rupees)	27723.2	22857.5
Gross income (Rupees)	39100	40640
Net income (Rupees)	11376.8	17782.5
Yield(kg/ac)	1920	1950

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	**Technical Efficiency**	**Allocative Efficiency**	**Economic Efficiency**
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 indicating that 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 showing that they use more input to get maximum output, whereas the allocative efficiency is 67 per cent indicating that 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 indicating that they are highly efficient as shown in table 3.

Table 4: Reasons for non-adoption of UAV technology

Sl. No	**Adoption**	**RPI**	**Rank**
1	**Land size (small and marginal farmers)**	**0.875**	**1**

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

Sl. No	Adoption	RPI	Rank
1	**Transport Vehicle**	**0.726**	**1**
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

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, which is 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.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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