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Unmanned Aerial Vehicle Direct Seeding Versus Ground Seeding Mechanization Services in Smallholder Farming Systems of North West IGP on Energy Use Efficiency and Quality of Rice Culture: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Various sectors use AI technologies to increase output and productivity. AI in agriculture also enables farmers to boost productivity while minimizing harmful environmental effects. AI is transforming the food-processing industry, where agricultural emissions have dropped by 20%. Mechanization is once again one of the top development policy targets for changing the smallholder agricultural system in the north west IGP. To support public investment or company development programs, however, previous and ongoing efforts frequently suffer from a lack of scientific data on end-user effective demand for various sorts of mechanical improvements. Rice production involves intricate agronomic procedures. Seeding, fertilizing, and pesticide application are labour- and time-intensive tasks that have low automation efficiency. Currently, a lot of research focuses on the single UAV operation on rice, but there aren't many applications that cover the entire process of sowing, fertilizing, and applying pesticides. Based on the intelligent operating platform, a mUAV was created to oversee the planting of rice. This aircraft accomplished three tasks on the same flight platform: seeding, fertilizer application, and pesticide application. Machine design was carried out using simulations of CFD. The cultivation patterns of mechanical rice direct seeder, mechanical rice transplanter, and mUAV seeding were compared to perform a comparative evaluation of the entire process. With improved rice automation, fewer labour inputs, and lower costs, it is intended that this evaluation will offer new machinery for rice farming patterns in various conditions.

Keywords: Mechanisation; unmanned aerial vehicle; direct seeded rice.

ABBREVIATIONS

AI	:	*Artificial Intelligence;*
BR	:	*Broken Rice;*
CFD	:	*Computational Fluid Dynamics;*
DSR	:	*Direct Seeded Rice;*
HR	:	*Head Rice Recovery;*
IGP	:	*Indo-Gangetic Plains;*
KLAC	:	*Kernel Length after Cooking;*
mUAV	:	*Multifunctional Unmanned Aerial Vehicle;*
UAVs	:	*Unmanned Aerial Vehicles.*

1. INTRODUCTION

AI is a developing technology in the agricultural industry. The agricultural system nowadays has been elevated by AI-based machinery and equipment. With the use of this technology, crop output has increased along with real-time tracking, harvesting, processing, and marketing [1]. The use of drones and agricultural robots in automated systems has significantly impacted the market for products based on agriculture. In order to recognize different significant parameters, such as weed detection, crop quality and yield detection, among many other ways, several high-tech computer-based systems have been developed [2].

One of the most significant crops in the world is rice. Rice is grown in more than 100 countries and is a staple meal for more than half of the world's population, with Asia accounting for 90% of production [3,4]. About 40 million hm2 of India are used for rice farming, which accounts for 25% of the world's rice cultivation area and 35% of India's cropland. In India, about 25 million tons of rice are produced annually, which accounts for 50% of the country's grain production and 45% of the world's rice production [5,6]. Since rice is a staple food for 70% of Indians and has the biggest yield and the largest area under cultivation, it plays a crucial role in ensuring food security [7]. However, the cultivation of rice involves numerous steps and intricate agronomic technical procedures, which result in a low-efficiency mechanization of the entire production process. The levels of mechanization for rice seedling, transplanting, managing fertilizer and pesticides, machine harvest, postharvest transportation, and grain drying varies significantly [8]. Tillage, seeding, management, and harvest are the four basic steps in the rice cultivation process. Although the tillage and harvest are automated, modern agricultural demands cannot yet be met by seeding and management practices [9,10].

The arable land is sparse and dispersed, especially in hilly locations where the terrain is challenging. The usage of mechanical activities on the plains also has issues. For instance, the usage of small farm equipment is inconvenient and the compacted soil causes uneven seed emergence [11]. They are labour-intensive, time-consuming, and inconvenient, which has a negative impact on the advancement of automation [12,13]. Numerous types of agricultural machinery are employed in the production of rice as a result of the growth of contemporary manufacturing. UAVs have been employed extensively in the production of rice due to their benefits of having less site requirements, low energy consumption, high safety, and no space limits [14]. Numerous academics have used UAV applications for rice management as a result of the ongoing advancements in agronomic technology, intelligent supporting technology, and equipment for the entire process of producing rice [15,16]. First, there have been some prior investigations into the impact of plant protection UAV operation parameters on droplets and control efficacy. Small, unmanned helicopters' spray parameters and the deposition of droplets were researched by Wang et al., [17]. The experimental findings demonstrated that the droplet distribution reduced with increasing flight speed and dropped from the upper to the lower layer of the rice canopy. UAVs are currently widely used in many facets of agriculture; however, they typically serve a single purpose. In agricultural applications including disease and insect pest control, pollination, and the remote acquisition of agricultural information, UAV technology has advanced quickly, but the development of UAV air sowing has lagged behind. The idea to create a mUAV is offered (Fig. 1) based on the features of several UAV applications in rice production, including planting, fertilization, and pesticide application.

The following aspects were primarily the subject of this article:

(1) The modular structure of the mUAV's various functionalities. A sophisticated flight platform that was built on the modular design philosophy and coupled to various functional devices, with the various modules standing for various functions, was created and refined. This configuration might improve machinery use and decrease agricultural machinery idleness. Additionally, it might lower the price of purchasing agricultural equipment while safeguarding farmers' revenue.
(2) For the various functional modular devices, the right set of operational characteristics was chosen. The operating patterns were each evaluated separately using two methods. Prioritization was given to numerical simulation analysis, which concentrated on controlling downwash airflow motion. The particle distribution at the target under the influence of downwash airflow was then clarified by combining field experiments for verification. It was believed that the information in these studies would offer farmers some useful advice.
(3) Comparative field tests in the mUAV, mechanical sowing, and mechanical transplanting—the latter two being the most common mechanized tasks in daily life—were carried out. To compile and analyse the effects of labour cost and rice production throughout the entire process of rice cultivation, each of the three types of equipment was applied to the entire rice-growing process. When farmers decided to use the mUAV for their operations, it was hoped that the comparison test would help them realize and comprehend the benefits and drawbacks of the device [18].

Rice direct seeding has drawn a lot of interest recently as an easy and practical seeding technique [19,20]. Year after year, the amount of mechanized rice direct sowing in IGP has increased [21]. Additionally, UAV seeding of rice has emerged as an operational approach with the development of agricultural UAV [22,23,24]. UAV seeding has advantages over ground-based machinery in terms of flexibility, high efficiency, and labour savings [25,26]. However, the majority of seeding UAVs are more frequently employed for broadcast seeding, which results in seed uniformity that is inferior to that of row seeding [27,28]. The uneven development density of rice seedlings caused by broadcast sowing is more likely to cause poor ventilation and lodging [7]. Row seeding can enhance seed uniformity, which helps compensate for broadcast seeding's drawbacks [29]. Currently, a few academic institutions and businesses have conducted pertinent studies on UAV seeding. Wu et al., [30] created a centrifugal rice broadcast seeding system, selected the best operating conditions through simulation experiments, and then confirmed the viability of the broadcast seeding system through bench tests and field trials. The majority of the seeding UAV models launched by several UAV firms used pneumatic broadcast seeding or centrifugal disc seeding technologies, which cannot be used for row seeding operations [31,32]. Huang et al., [33] built and tested an auxiliary seeding device based on a centrifugal rape seeding equipment in order to implement UAV-based row seeding.

The research described above on UAV direct seeding had the following drawbacks:

(1) Some of the researches only improved the uniformity of the broadcast seeding, but still cannot realize sowing in rows;
(2) To reduce the influence of UAV wind on seeding accuracy, the seed outlet was closer to the ground, which posed a greater safety hazard;
(3) In order to achieve multi-row seeding, the entire machine had to be huge, which made transportation difficult;
(4) The ability to accelerate the seeds was insufficient or the structure wasn't appropriate for UAV row sowing.

This research created a brand-new shot seeding mechanism for rice that can be transported on a UAV to solve the aforementioned issues.

Table 1. Benefits of DSR by UAV and challenges with ground seeding mechanization of rice

Benefits of Direct Seeding of Rice by UAV Services	Challenges with Ground Seeding Mechanization Services of Rice
➢ Quick, easy and highly efficient	➢ Time consuming, laborious and efficiency varies with skill of the operator
➢ No/ minimal operational exposure. Safe to operate	➢ Exposure of the operator
➢ Less water consuming	➢ More water consuming
➢ Precision and uniform coverage	➢ Only small area can be covered
➢ Adaptable to undulated terrain, steep slopes, wet muddy fields, and inaccessible heights such as tall trees	➢ Can be operated efficiently up to certain height only
➢ Higher return on investment	➢ Low return of investment

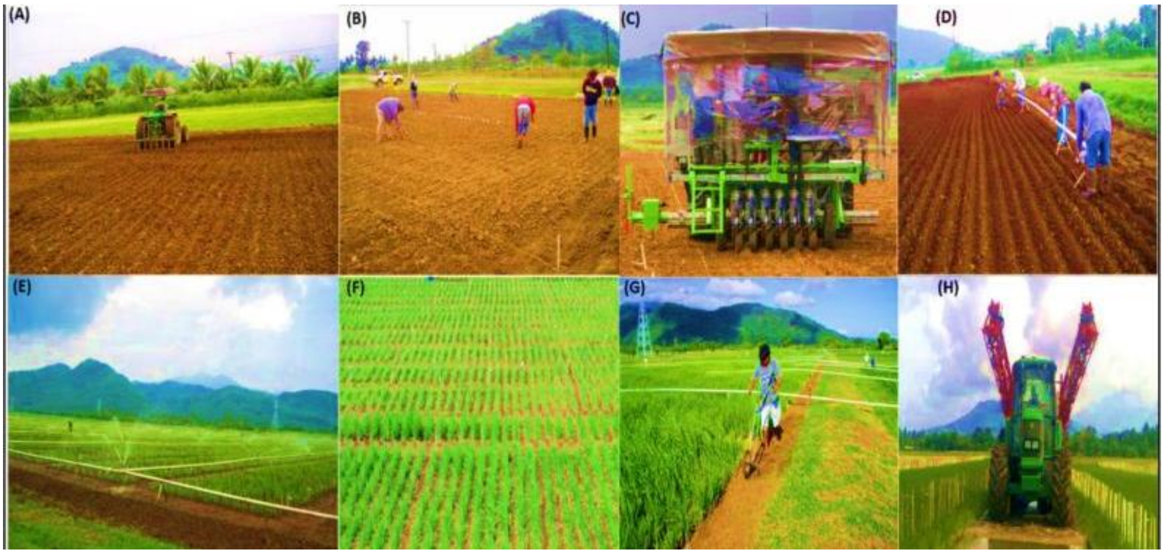


Fig. 1(a). Agricultural procedures used in rice growing systems that mechanize ground planting: Land preparation, manual seed sowing, mechanized seed drilling, sprinkler irrigation system installation, sprinkler irrigation at the seedling stage, field view of a DSR field at the seedling stage, manual weed control with a wheel hoe, and mechanized weed control with a boom tractor sprayer are shown in (A), (B), (C), (D), (E), (F), (G) and (H) respectively

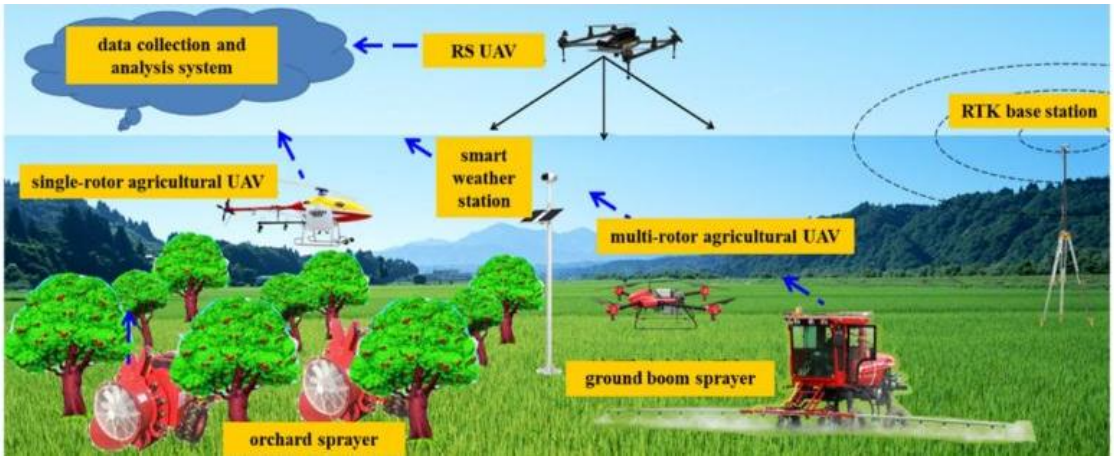


Fig. 1(b). Agricultural procedures used in rice growing systems that UAV planting

The use of UAVs and ground seeding mechanization by the community of smallholder farming systems in the nation and the state has advanced significantly. Farmers are now able to make prompt and precise interventions since they have access to real-time information on the health of their crops thanks to the use of UAVs for crop monitoring. As a result, pest management has improved, chemical inputs have decreased, and crop output as a whole has increased. Additionally, the incorporation of ground seeding machinery has made it easier to evenly and precisely sow seeds, improving plant density and encouraging larger yields. These technological developments have given smallholder farmers more power, increasing their effectiveness, productivity, and means of subsistence while promoting the sustainable growth of agriculture in the region and the state.

2. TECHNIQUES FOR IMPROVING QUALITY OF RICE GRAIN

In various production systems, crop husbandry and management techniques can aid in enhancing the quality of rice grains. The choice

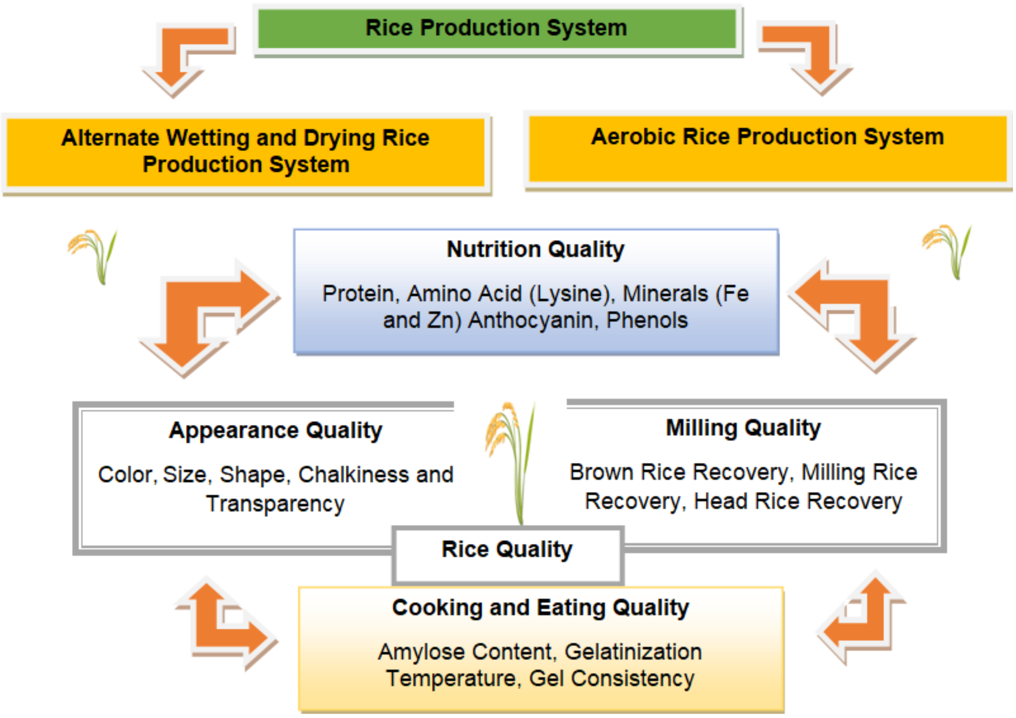


Fig. 2. Impact of quality of rice culture by rice production methods
[34]

of acceptable types, seed priming, soil, nutrient, and water management, planting crops at the ideal time, maintaining the ideal plant population, and integrated weed management measures are a few examples of these crop husbandry and management alternatives [34].

Grain quality is significantly impacted by rice cultivation methods. In this sense, grain quality in the flooded transplanted rice system is frequently better than that in the direct seeded aerobic rice system. When compared to transplanted flooded rice, the kernel amylopectin level of grains from direct seeded aerobic rice was much lower (9%). Additionally, the direct seeded aerobic rice system had considerably more opaque kernels, abortive kernels, and chalky kernels than the transplanted flooded rice. However, periodic flooding (alternate wetness and drying) significantly increased the kernel protein content of both white head rice and brown head rice in both direct seeded and transplanted rice systems. Additionally, intermittent flooding (alternate soaking and drying) in both direct seeded and transplanted rice systems was found to significantly reduce opaque kernels, abortive kernels, and kernel chalkiness when compared to direct seeded aerobic rice [34].

3. COMPARISON OF ENERGY USE EFFICIENCY BETWEEN FULLY MECHANIZED UAV AND SEMI-MECHANIZED IN SMALLHOLDER FARMING SYSTEMS OF RICE PRODUCTION

Rice production is often semi-mechanized in IGP, involving numerous labour-intensive and expensive processes, such as seedling planting, fertilizer application, and pesticide spraying. Compared to corn and wheat, rice production is more difficult and expensive to mechanize. Indian farmers' incentive to grow rice has been steadily dropping, particularly in light of the labour shortage and rising expenses. In order to boost Indian farmers' passion for rice cultivation, it is important to realize fully mechanized rice production with minimal human labour and expensive inputs. Mechanized rice transplanting has advanced quickly because it offers benefits and produces yields that are similar to those of traditional hand transplanting. The level of agricultural mechanization has been rising as subsidies for the purchase of agricultural machinery have expanded. The complete mechanization of rice production, with a

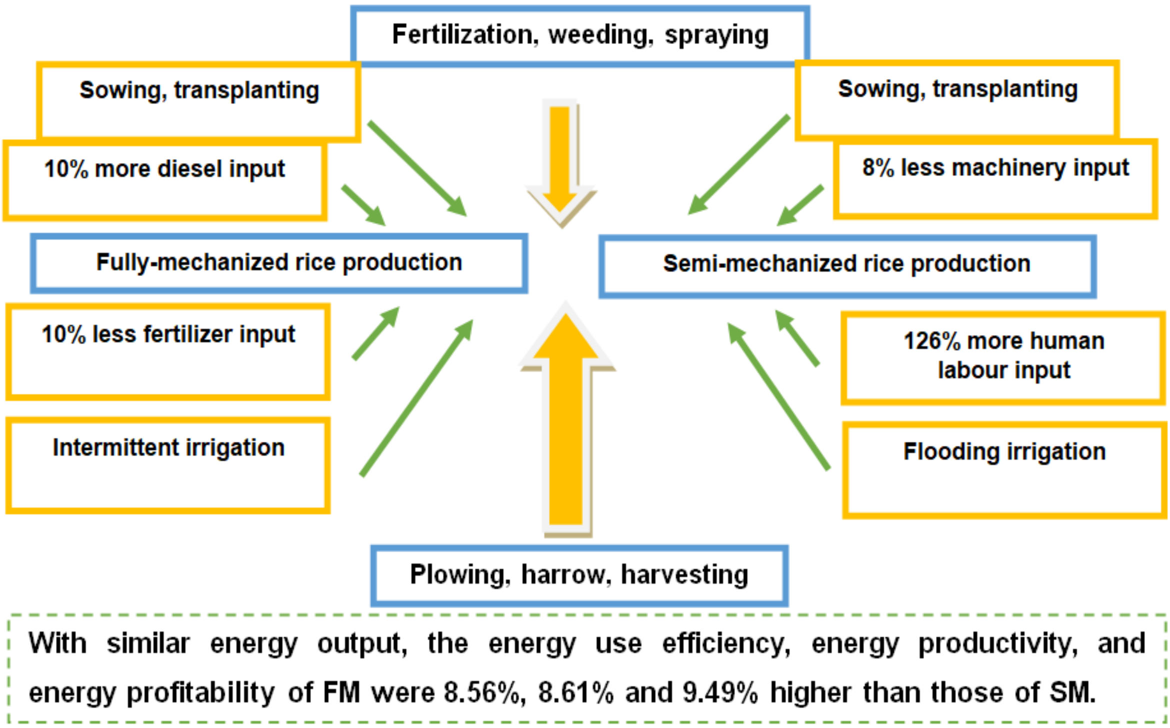


Fig. 3. Comparison of mechanized and semi-mechanised rice production system on energy use efficiency of rice
[35]

concentration on robotic rice transplanting, has a great deal of promise to solve the Indian farmers' waning interest in rice farming. Fully automated rice production can meet the public need for food security due to its high operational efficiency and appealing yields as compared to semi-mechanized rice production. However, as the mechanization of rice production has increased, costs for fuel, seeds, and machinery upkeep have been rising quickly, and energy inputs have been increasing exponentially. Increases in greenhouse gas emissions and deterioration of the water and soil environments are typically linked to the rise of these inputs [35].

4. PHYSICAL CHARACTERISTICS

Rice de-hulling is one of the crucial post-harvest procedures. The recovery of rice is also boosted by a high hulling percentage. Comparing cultivated scented rice varieties with basmati rice, the hulling percentage was determined (Table 2). The percentage of hulling varied between 63% and 81% among cultivars of scented rice. Haryana Basmati recorded 80.5%, Basmati -370 (80.3%), and Super Basmati (78.7%) had higher hulling percentages than Pusa Basmati-1 (80.8%) and Pant Dhan -12 (63.1%), respectively. The ideal rice hulling characteristics are eighty percent or higher. The number of whole grains that were weighed following industrial processing is indicated by the term head rice recovery. Over 65% of HR recovery is desirable, making it one of the most significant characters for quality evaluation. The HR measures the percentage of whole grains in the milled rice. For cultivated basmati and scented rice varieties, the hulling percentage ranged from 72 to 82 (Table 2). The preferred hulling percentage is greater than 80 percent, according to [36] and as the hulling percentage rises, so does the head rice recovery. Hot-air drying causes irregular cracks in rice, but long-term soaking of wet paddy tends to heal them [37]. According to a report, the HR value of a good rice variety should be at least 70%. The grain type, farming methods, and drying conditions all affect the HR value [38]. The percentage of BR grains in high yielding rice varieties varied from 5.3 to 36.3. The L/B ratio varied between 2.1 and 4.8. The variety "Pusa Basmati-1" had the highest L/B ratio, and "Pant Dhan -10" had the lowest. The L/B ratio varied between 3.6 and 4.8 among basmati varieties, with "Pusa Sugandh-3 and Type 9" having the lowest ratio. The varieties of rice that were compiled were divided into five groups based on the L/B ratio: "Basmati 370" (long slender), "Tarore Basmati and Super Basmati," "Haryana Basmati, Vallabh Basmati-21 and Type -3," "Pusa Sugandh-5," "HKR"," and "CSR"30Girga." (Medium slender) and categorises all basmati rice varieties as having extra-long slender grains (Table 2). After examining a few popular brands of basmati rice, [39] found that the L/B ratio varied between 4.5 and 4.8.

5. QUALITIES OF COOKING

KLAC for aromatic traditionally grown rice varied from 2.3 to 3.76 mm and from 4.62 to 5.88 mm for basmati rice. The "Tarori Basmati" and "Basmati -370" samples had the lowest KLAC values (Table 3).

Among each of the 18 cultivars used in this study (Table 4.), the value of the physico-chemical characteristic of the grain, such as amylase content is shown in Table 4. The studied varieties' amylose contents ranged from 19.5-25.5%, with a mean value of 22.9±2.01%. The highest concentrations of amylose were found in "Super Basmati" and "Basmati-370," followed by Pusa Basmati-1, Tarori Basmati, Haryana Basmati, and Pusa 2511. The least amount of percentage amylose was recorded by the Pant Dhan-10, Pant Dhan-12, NDR-118, CSR-30, and HKR-1 samples (Table 4). In comparison to basmati rice varieties, the majority of the aromatic varieties displayed low AC content (Table 4). According to [40], the AC for all rice grades was between 20.7 and 21.4%. Low AC causes cooked rice to become wet and sticky.

6. PERFORMANCE TEST FOR UAV DSR

Above the home-made mud trough (2.5 m x 2.0 m, 5 cm deep), a UAV DSR seeding test was conducted. Fig. 6a displays the location of the test. To digitize each seed's position, the image recognition technique was employed to get its position coordinates. The UAV's working height was 1.5 meters, its flying speed was km/h, its friction wheel's speed was 8000 revolutions per minute, and its metering wheel's speed was 15 revolutions per minute. Three times were given the test. Liu et al., [41] took images at a height of 3 m from the mud trough with natural lighting, and the resolution of the colour image recorded was 2250 x 4000.

Table 2. Effects on the physical quality of the rice grains through ground seeding mechanization services of crop establishment

Varieties	Moisture content (%)				Hulling rate (%)				Milling rate (%)				Head rice recovery (%)			
	ZT-TPR	RT-TPR	W Bed-TPR	CT-TPR	ZT-TPR	RT-TPR	WBed-TPR	CT-TPR	ZT-TPR	RT-TPR	WBed-TPR	CT-TPR	ZT-TPR	RT-TPR	WBed-TPR	CT-TPR
Pusa-2511	13.4	13.3	13.7	13.6	74.3	77.4	79.2	78.1	64.7	64.3	67.1	65.5	57.2	58.5	56.1	59.2
Type-3	11.4	11.2	11.9	11.7	76.5	77.2	79.3	78.2	65.1	64.9	68.5	64.7	54.5	55.1	54.7	56.1
Type- 9	11.7	11.4	12.5	12.1	75.2	77.1	80.9	79.8	64.5	64.1	65.3	65.1	54.1	55.4	54.4	55.9
Tarori Basmati	12.3	12.1	12.9	12.6	72.4	78.3	78.4	74.9	63.7	63.9	64.4	64.2	53.7	54.2	53.9	55.1
Haryana Basmati	12.6	12.4	13.1	12.8	73.4	80.5	80.7	77.2	64.4	64.1	65.6	64.9	53.9	54.9	54.1	55.8
Pusa Basmati-1	12.9	12.6	13.4	13.3	72.7	80.8	82.5	79.6	67.4	66.9	69.1	68.4	58.1	59.2	60.4	59.8
Basmati-370	13.4	13.2	14.0	13.7	80.7	80.3	81.3	75.6	72.3	71.3	74.2	73.1	56.8	57.6	55.7	58.1
Super Basmati	13.7	13.4	13.8	13.8	77.6	78.7	80.1	74.2	71.0	70.8	73.4	69.4	68.2	63.9	68.9	59.4
Basmati- 386	12.4	12.1	13.3	12.9	74.2	75.6	76.2	72.1	68.2	67.6	71.1	70.8	67.5	65.8	68.9	68.0
Ranbir Basmati	11.6	11.1	12.6	12.2	74.6	75.1	76.8	75.5	70.8	69.0	71.5	70.6	67.0	65.1	68.2	67.4
Vallabh Basmati-21	9.5	9.2	11.2	10.8	77.2	78.1	79.9	78.5	71.5	70.8	72.6	72.1	67.9	66.7	68.5	68.1
Pusa Sugandh-2	8.9	8.5	10.1	9.7	76.9	77.2	78.6	77.9	71.3	71.1	73.4	72.8	59.3	58.0	62.3	60.4
Pusa Sugandh-3	11.7	11.3	12.4	11.9	76.8	77.8	78.4	76.8	70.6	69.7	71.1	70.7	58.1	57.3	59.9	58.3
Pusa Sugandh-5	11.6	11.2	12.1	11.7	76.4	77.3	77.9	76.5	69.2	68.1	70.2	69.5	55.9	54.2	57.7	56.1
Mugadh Sugandh	12.2	11.9	13.4	12.9	75.6	76.1	77.2	75.8	66.9	64.2	68.3	67.1	57.2	55.3	59.1	58.2
Pant Dhan-10	12.8	12.1	13.7	13.1	82.6	65.5	83.4	82.8	70.2	69.2	71.9	71.1	54.6	53.1	56.7	55.0
Pant Dhan-12	12.6	11.9	13.2	12.8	80.9	63.1	82.4	81.1	68.1	64.0	69.2	68.6	56.1	55.4	57.5	57.1
CSR-30	12.5	11.7	13.3	12.6	77.8	72.4	81.4	80.7	67.2	66.7	70.1	67.9	55.8	53.1	57.2	56.4
HKR-1	11.4	11.2	13.1	12.9	79.7	72.3	82.1	81.4	65.2	64.0	69.1	68.6	56.1	54.2	59.2	57.8
NDR-118	10.6	10.8	11.6	11.3	79.9	73.3	81.9	80.8	64.2	62.4	68.4	67.6	54.1	52.7	55.3	54.8

ZT-TPR- Zero till transplanted rice; RT-TPR- Reduced till transplanted rice; W Bed-TPR- Transplanted rice on wide raised beds; CT-TPR- Conventional-till puddled transplanted rice

Table 3. Effects on the quality of cooked rice grains through ground seeding mechanization services of crop establishment

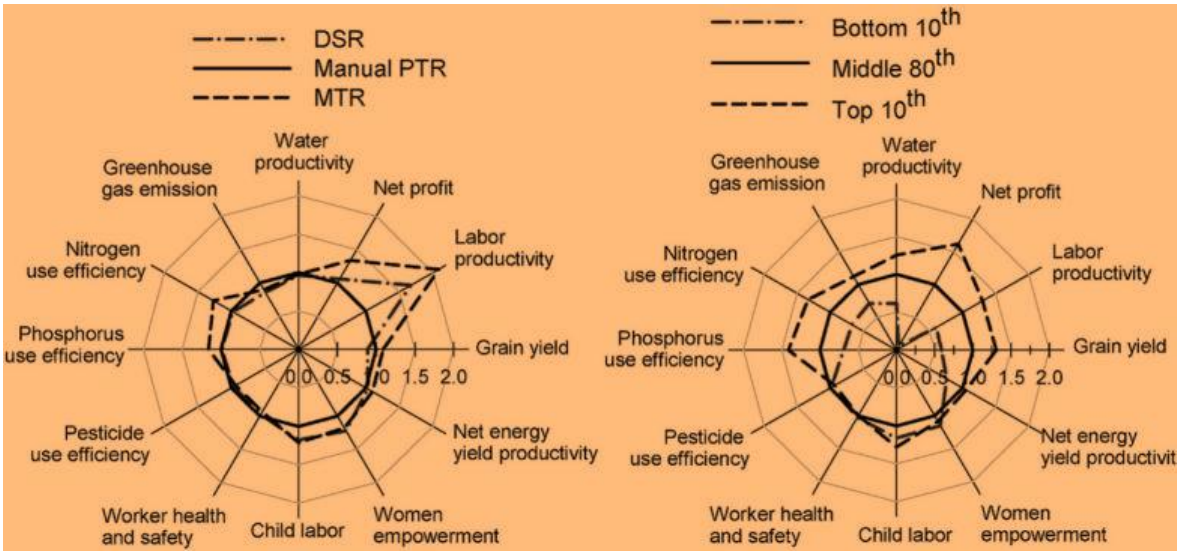
Varieties	Kernel length (mm) after Cooking				Kernel width (mm) after Cooking			
	ZT-TPR	RT-TPR	WBed-TPR	CT-TPR	ZT-TPR	RT-TPR	WBed-TPR	CT-TPR
Pusa-2511	7.2	7.1	8.2	7.3	2.4	2.1	2.8	2.6
Type-3	7.4	7.2	7.9	7.7	2.7	2.4	3.1	2.8
Type- 9	7.5	7.1	8.1	7.9	2.6	2.2	3.1	3.1
Tarori Basmati	8.1	7.9	9.1	8.9	2.3	2.1	2.8	3.3
Haryana Basmati	7.8	7.6	9.0	8.8	2.6	2.4	3.0	2.9
Pusa Basmati-1	7.4	7.7	8.8	8.6	2.3	2.1	2.8	2.7
Basmati-370	8.5	8.4	8.1	8.1	3.0	2.9	2.8	3.0
Super Basmati	8.8	8.7	9.1	9.3	2.7	2.6	3.1	2.5
Basmati- 386	8.1	7.8	8.9	8.7	2.6	2.5	3.2	2.8
Ranbir Basmati	7.9	7.6	8.8	8.5	2.4	2.2	2.9	2.7
Vallabh Basmati-21	7.3	7.1	8.1	7.8	2.6	2.3	3.0	2.8
Pusa Sugandh-2	6.9	6.9	7.7	7.5	2.1	1.9	2.5	2.3
Pusa-Sugandh-3	7.1	7.3	7.8	7.7	2.3	2.1	2.8	2.6
Pusa-Sugandh-5	7.3	7.5	8.0	7.9	2.7	2.6	3.0	2.9
Mugadh Sugandh	6.9	7.2	7.5	7.3	2.3	2.2	2.9	2.7
Pant Dhan-10	6.1	6.4	7.0	6.3	1.9	1.7	2.4	2.2
Pant Dhan-12	6.3	6.6	7.1	6.6	2.0	1.8	2.6	2.3
CSR-30	6.7	7.1	7.6	7.5	2.4	2.2	2.8	2.6
HKR-1	6.4	6.6	7.6	7.3	2.5	2.2	3.0	2.8
NDR-118	6.9	7.5	8.0	7.9	2.4	2.2	2.9	2.7

ZT-TPR- Zero till transplanted rice; RT-TPR- Reduced till transplanted rice; WBed-TPR- Transplanted rice on wide raised beds; CT-TPR- Conventional-till puddled transplanted rice

Table 4. Effects on the characteristics of cooked grains through ground seeding mechanization services of crop establishment methods

Varieties	Alkali spreading value				Amylose content (%)				Minimum cooking time (Min)			
	ZT-TPR	RT-TPR	WBed-TPR	CT-TPR	ZT-TPR	RT-TPR	WBed-TPR	CT-TPR	ZT-TPR	RT-TPR	WBed-TPR	CT-TPR
Pusa-2511	5.6	5.2	5.7	5.9	18.6	18.2	20.2	21.8	15.1	16.2	14.8	14.3
Type-3	5.8	5.3	5.9	6.1	19.4	19.2	21.4	22.3	14.6	15.9	13.5	12.9
Type- 9	5.6	5.3	5.7	6.2	19.6	19.0	21.2	24.9	16.0	17.1	15.6	13.6
Tarori Basmati	6.0	5.9	6.5	7.1	19.8	19.3	23.1	24.5	9.2	11.0	7.5	6.7
Haryana Basmati	6.3	6.1	6.6	6.8	20.2	19.8	23.6	24.8	11.2	12.9	9.5	8.1
Pusa Basmati-1	6.4	6.0	6.4	6.6	20.3	19.9	24.1	25.1	12.8	14.5	11.1	9.7
Basmati-370	6.5	6.2	6.7	6.9	20.7	20.2	24.9	25.2	13.5	15.2	12.9	10.3
Super Basmati	5.7	5.5	5.8	6.2	21.4	21.1	25.1	25.5	16.2	18.9	13.2	11.1
Basmati- 386	6.0	5.8	6.2	6.4	20.9	20.6	24.1	25.3	14.3	16.0	12.2	9.5
Ranbir Basmati	5.9	5.7	6.0	6.3	21.9	21.4	25.4	27.1	14.9	17.9	12.	9.2
Vallabh Basmati-21	4.7	4.5	4.9	5.2	27.9	27.4	28.6	30.3	15.0	17.6	14.3	12.7
Pusa Sugandh-2	5.2	5.0	5.4	5.7	28.1	28.0	29.4	31.9	16.5	18.7	15.1	13.0
Pusa-Sugandh-3	5.4	5.1	5.6	5.8	23.5	23.2	24.2	25.0	18.1	19.3	15.2	13.6
Pusa Sugandh-5	5.6	5.2	5.5	5.9	22.5	21.8	22.9	23.8	17.5	18.5	16.1	13.9
Mugadh Sugandh	5.5	5.0	5.6	5.8	23.5	23.1	24.0	24.8	20.2	22.3	18.0	14.3
Pant Dhan-10	3.6	3.2	3.8	4.1	15.4	15.2	16.5	17.7	25.3	28.4	20.1	24.3
Pant Dhan-12	3.7	3.3	3.9	4.3	16.9	16.4	17.6	18.3	32.1	35.3	30.5	28.0
CSR-30	5.4	5.1	5.6	5.8	17.1	16.9	17.9	18.7	18.2	22.3	17.5	15.2
HKR-1	5.3	5.0	5.4	5.6	16.5	16.2	17.4	18.1	19.5	23.1	18.1	15.6
NDR-118	4.7	4.3	5.0	5.2	16.3	15.8	16.8	17.2	21.1	26.7	19.1	15.9

ZT-TPR- Zero till transplanted rice; RT-TPR- Reduced till transplanted rice; WBed-TPR- Transplanted rice on wide raised beds; CT-TPR- Conventional-till puddled transplanted rice



Each panel's left-hand figures summarize input utilization, and the right-hand figures summarize performance metrics.

Fig. 4. Comparisons between three distinct establishment methods, the types of farmers, and various production inputs and performance measures

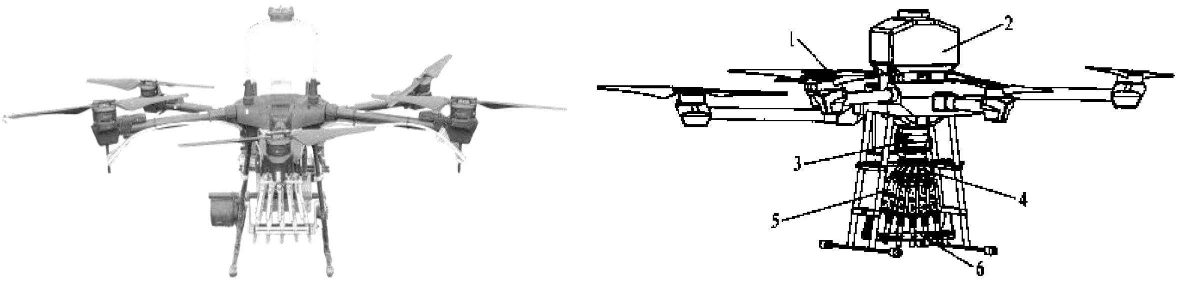
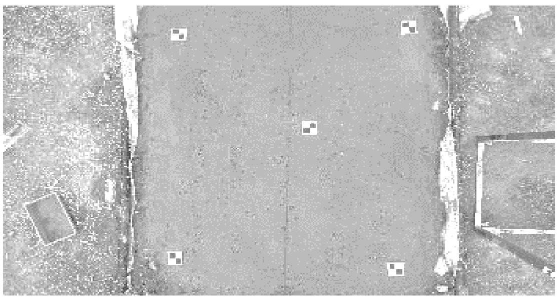


Fig. 5. A Device for UAV Rice Seeding

1. UAV platform 2. Seed box 3. Seed-metering device
4. Seed distributor 5. Shot seeding module 6. Angle adjustment mechanism

6a. Sowing in the mud trough

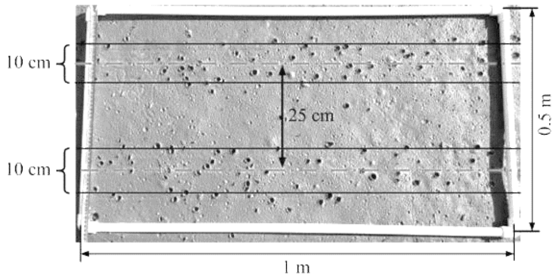


6b. Original image of seed trajectory

Fig. 6. UAV seeding performance experiment

An experiment using field UAV seeding was conducted at the Agricultural University. Before planting, the field should have undergone rotary tillage, beating, and leveling procedures in accordance with the agronomic requirements for direct seeding of rice. The shot seeding operation was carried out in the autonomous flight mode once the route planning was finished, and the actual operation area was 0.252 hm^2. In Fig. 7a, the seeding scene is depicted. The rice variety used in this test was 19 Xiang, and the seed weighed 21.4 g per thousand grains. The seedling emergence rate of pelletized seeds, as tested under laboratory circumstances, was 86.20%. The thousand-grain weight of the seeds after palletization was 70.0 g. The seed metering wheel rotated at a rate of 15 revolutions per minute, the working height was 1.5 meters, the row spacing was 25 centimeters, and the friction wheel speed was 8000 revolutions per minute. The flying speed was set at 3.6 km/h. It is possible to compute the theoretical seeding rate as 38.56 kg/hm^2. The emergence rate was measured using the five-point sampling technique. As illustrated in Fig. 7b, outline the sampling area with a rectangle frame (0.5 m 1 m), and take two neighboring rows in each sampling region. The number of seeds in the sampling area was counted, and starting on the sixth day following sowing, the number of rice seedlings was recorded. After the rice was fully grown, the yield was assessed using traditional field management techniques. The fresh grains were weighed before being harvested with the rice harvester to determine the yield. The moisture content of rice was tested using a grain moisture analyzer, which converted the weight of the fresh grain into a weight at 13.5% moisture content and then subtracted contaminants at 1% to get the final dry grain quality [41].

7 a. Seeding operation in field



7 b. Seed traces on the ground and sample area

Fig. 7. UAV planting with seeds on the surface of the mud

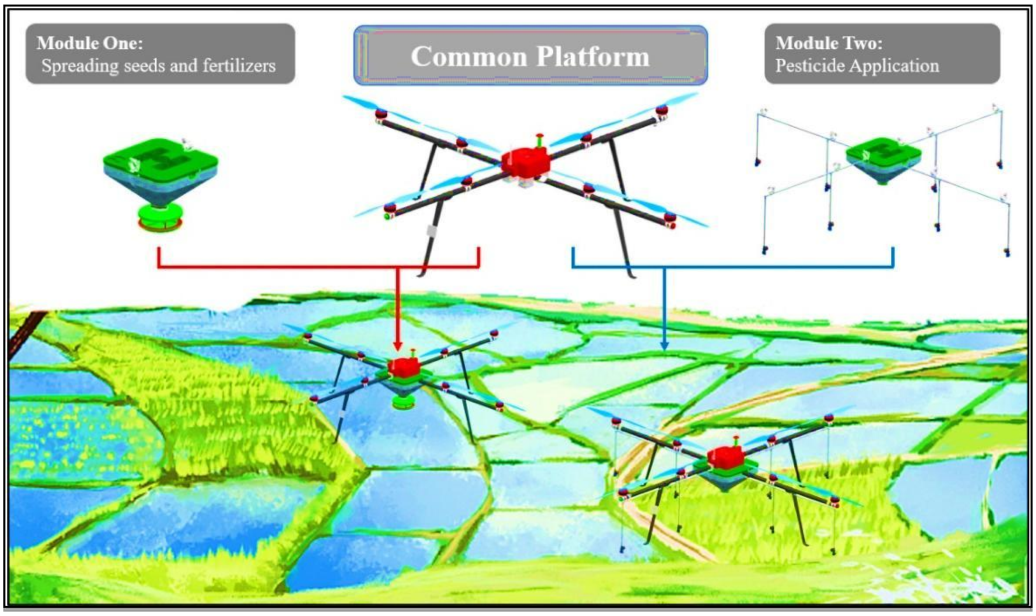


Fig. 8. mUAV total design solution

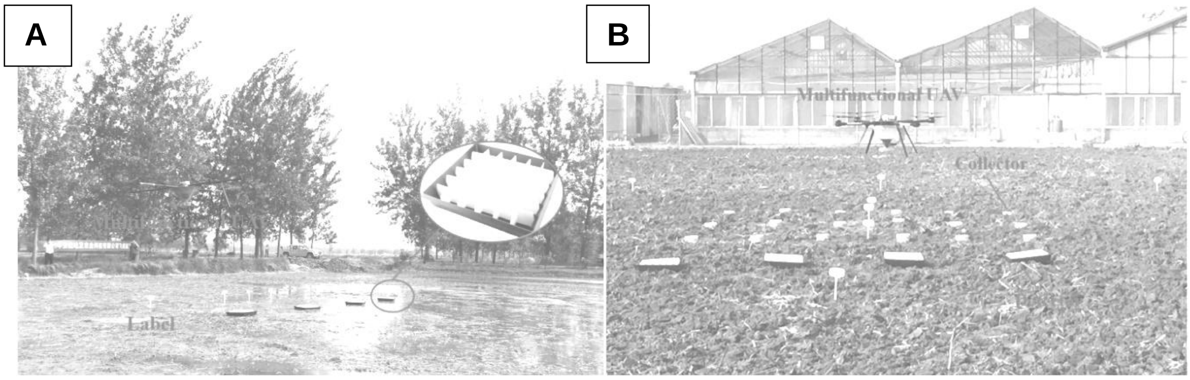


Fig. 9. Shows the test site for fertilizing and seeding rice

(A) Shows the position of the rice seeding test site, where the detector will collect any rice seeds that fall to the ground. (B) Shows a representation of a fertilizer spreading test site where ground fertilizer particles are collected using a detector and another method using a collector

Fig. 10. Test site for applying pesticide to rice

The field sample location for a rice field is shown in (A), where the sampling sites are organized on a fixed rod. The double-head clamp that joins each fixed rod to the droplet collector is shown in (B) as a partial schematic of each fixed rod

7. DISCUSSION

In comparison to other techniques, UAV seeding in smallholder farming systems for rice cultivation offers significant cost reductions. Using traditional manual seeding techniques frequently causes uneven seed dispersal, which results in poor plant density and lower crop yields. As opposed to this, UAVs with precision seeding technology provide precise and uniform seed planting, enhancing plant density and increasing production potential. Using less seed than necessary thanks to this precision sowing results in lower seed acquisition expenses. UAV seeding additionally enables targeted seed placement, eliminating waste and lowering the overall seed required. UAV seeding is a cost-effective method for growing rice and a useful tool in smallholder farmers' agricultural methods due to the efficient use of seeds, which results in significant cost savings for them.

With the growing use of UAVs in precision agriculture, CFD was used to optimize the downwash airflow of agricultural UAVs, and the particle motion in the airflow was analysed. The use of UAVs in the entire rice cultivation process or in isolated segments might be considered as meeting the needs of modern paddy agriculture. Jiyu et al., [42] employed a tiny multi-rotor UAV for rice broadcasting and discovered that the CV was much lower than that of artificial broadcasting. The average yield of UAV-broadcast field was 7,705.5 kg/hm2, indicating that UAV-broadcast rice air was viable. Mechanical transplanting, unmanned machine seeding, mechanical precision hole sowing, mechanical seedling throwing, and manual seeding were all tested in a comparative trial by Zhu et al., [43]. The results revealed that, in descending order, human seeding, UAV seeding, mechanical precision hole sowing, mechanical transplanting, and mechanical seedling flinging produced the most seedlings. The overall effective number of spikes was higher in the unmanned seeding and mechanical transplanting treatments. Mechanical precision hole sowing, mechanical seedling throwing, UAV seeding, mechanical transplanting, and manual seeding had the highest theoretical yields. The labour cost study in the seedling planting process revealed that the mechanical precision hole sowing or UAV seeding approach deserved to be promoted. Zheng et al., [44] tested four seeding methods: mechanical powder seeding, precise hole direct sowing, UAV seeding, and hand planting. The results showed that the UAV seeding method produced the most seedlings and the most effective spikes, with the effective spikes reaching 3,811,500 spikes/hm2. UAV seeding produced a yield of 6,549 kg/hm2, which was 1.2% lower than mechanical precision hole sowing. Furthermore, the UAV broadcast had the lowest labour cost of 40.5 Yuan/hm2. The number of seedlings per square decreasing in descending sequence of mUAV direct seeder, mechanical rice direct seeder, and mechanical rice transplanter. Mechanical direct seeder, mUAV direct seeder, and mechanical transplanter had the lowest theoretical yields. With strict emission limits for environmental protection regulations and exhaust pollution limits for diesel engines of non-road mobile machinery [45], the UAV used electrical energy as power, as opposed to traditional agricultural machinery that burned diesel to obtain power, which reduced pollutant emissions. In this study, it presented a realistic solution for rice cultivation through the use of mUAV in sowing, fertilizing, and applying pesticides, which greatly contributed to labour reduction and mechanization enhancement. Furthermore, the cost of farm machinery varied throughout the three parts of seeding, fertilizing, and spraying. The total input cost of agricultural machinery employed in mUAV seeding, mechanical seeding, and mechanical transplanting was around 110, 215, and 235 thousand RMB, respectively. The tractor utilized in the mechanical direct seeder and transplanter test area, on the other hand, can also be used in the tillage stage. As a result, it decreased the cost of farm machinery inputs in the mUAV pilot region to some extent and raised the rate of farm machinery usage, but it also increased the rate of depreciation. At the moment, India's agricultural UAVs are largely employed for plant protection, whereas UAV broadcast applications are still in the early stages of research and testing. There are still numerous issues with UAV applications. The mUAV had no benefit over ground fertilization apparatus during the fertilization procedure. Despite a reduction in the number of personnel, the operating efficiency and labour costs were lower than those of ground machinery.

There were two primary methods of mechanical rice direct sowing in the soil preparation process: 1. water direct seeding and 2. dry direct seeding. Water direct seeding was mostly used in the south, where rice seeds developed in a levelled soil free of waterlogging. Dry direct seeding was largely used in the north, which allows for direct seeding without germination but has greater plot requirements. At this point, the mUAV pilot area outperformed the water broadcast pilot region in terms of labour expenses. However, as compared to dry broadcast, mUAV had no benefit. Rice seeds, on the other hand, must germinate before they may be disseminated. When the turntable was rotated too quickly, it collided with the wall, causing harm to the seed buds. The maximum range was also limited; the battery's continuous flying capacity was normally 10-20 minutes, resulting in a UAV work efficiency that could not be completely developed. The field operation necessitated the transport of numerous expensive batteries. It's also a challenge that the UAV industry is now dealing with. India, on the other hand, had 59.2% comprehensive rice mechanization, with tillage, sowing, and harvesting levels of 79.3, 24.5, and 67.1%, respectively. This is merely a transition from the primary to the intermediate stage, signalling that we must continue our efforts to fully resolve the problem of mechanization of rice farming in IGP. To establish a right path for itself, India should learn from modern equipment and technology of developed countries. Agricultural mechanization development in India cannot immediately imitate the path of another country, and agricultural mechanization in India can only be accomplished step by step.

8. CONCLUSION

All stages of production, from land preparation to harvest, should be mechanized if rice-growing farmers are to reap the rewards of mechanical rice cultivation. Farmers came to understand that automating the processes involved in producing rice results in labour and time savings while also being profitable. When compared to manual labour, fully mechanized major rice production activities from land preparation through harvesting can result in labour savings of up to ten times. However, in order for rice mechanization to be successful, local implement manufacturers and suppliers must make sure they provide high-quality, dependable products that won't deter farmers with little resources. A UAV-based DSR seeding device was created with the advantages of a small overall machine structure, simultaneous seeding of five rows, adjustable seed discharging rate, and steady seeding.

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DATA AVAILABILITY STATEMENT

In this investigation, no new data were collected or analysed.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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