International Journal of Innovative Research and Scientific Studies, 5(4) 2022, pages: 297-305

IJIRSS
International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

Impact of Autonomous Drone Pollination in Date Palms

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Abstract

Artificial pollination of date palms has been practiced over thousands of years to improve the fruiting traits in date palms. Due to the changes in agricultural practices in the modern period, mechanical pollination techniques were tried in some parts of the world. But machine pollination of date palms has not gained popularity worldwide owing to economic, environmental, or technical challenges. Of late, agricultural drones were introduced to pollinate date palms in significantly less time and reduce the risk of injury, manpower, and cost. Modern drones can have integrated, built-in smart data-collecting devices to provide the farmers with all relevant information. Although this autonomous method provides a number of benefits in terms of labor and cost, pollination time, ease of use, etc, studies have not yet entirely evaluated the efficacy of drone pollination on date palms. This paper summarizes the outcomes of an autonomous drone pollination study performed during the 2022 season in the orchards of Oman. The pros and cons of this artificial aerial pollination method are examined in the paper. The impact of this method of pollination on crop yield, fruit quality, and fruit set percentage are analyzed. This study also explores the limitations of the autonomous drone pollination system and throws light on ways to improve its efficiency.

Keywords: Aerial pollination, Date palms, Drones, Fruit set percentage, Liquid pollen suspension, Unmanned aerial vehicle.

DOI: 10.53894/ijirss.v5i4.732
Funding: This study received no specific financial support.
History: Received: 26 July 2022/**Revised:** 14 September 2022/**Accepted:** 30 September 2022/**Published:** 12 October 2022

Authors' Contributions: Both authors contributed equally to the conception and design of the study.
Competing Interests: The authors declare that they have no competing interests.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained.
Ethical: This study followed all ethical practices during writing.
Publisher: Innovative Research Publishing

1. Introduction

Eating dates and growing date palms is an important part of the tradition and culture of the people in the Middle East. Date production is currently accomplished by involving technology in the date palm cultivation process. The Date Palm is a flowering tree species in the palm family, Arecaceae, and is scientifically known as Phoenix Dactylifera, cultivated for its energy-packed fruit called dates [1]. It is a dioecious plant where the male palms produce pollens and female palms produce fruits [2]. Pollination in date palms occurs naturally by wind or insects. But this method does not ensure good fertilization enough to give economically feasible yield levels [3]. In order to improve the fruit set percentage (FSP), each female inflorescence is artificially pollinated. The artificial pollination of date palms is performed by manually placing the fresh male flower strands on the female flowers, for which the farmer climbs the male palm tree for its stamens and again climbs each female tree to place the required amount of male flower strands in the female flowers [4]. This method of pollination has been practiced over thousands of years, as it overcomes the shortcomings of dichogamy (where the male and female flowers mature at different intervals of time), sustains yield levels, and enhances the FSP. The major challenges with this method are the extreme labor involved, the risk of injury, the time required for the pollination process, and the increased cost of production [5].

Few non-conventional mechanical pollination techniques such as hand pollination with liquid pollens and a dusting of dry pollens using ground-operated mechanical dusters, have improved the date fruit production in terms of labor cost and/or time but may have compromised the date palm pollen (DPP) consumption and yield or vice versa [6]. These treatments were possible as the DPP can be extracted through manual and automated methods in an undamaged and viable state. However, recent studies have shown that the optimal method of pollination, considering parameters such as economic feasibility, DPP consumption, cost of labor, yield in terms of FSP, etc. is the use of liquid suspension sprays either manually or mechanically. This method shows reassuring results, with the lowest DPP consumption and highest fruit set percentage (FSP) compared to other treatments [6]. The liquid sprays were hand sprayed using pressurized pumps from the ground [7] which results in a huge waste of water and pollens. Also, this method works well only with short palm trees. On the way to achieving a balance between effective cost of production and high-quality yield, few farmers are incorporating smart and advanced technology into their farming practices to manage their crops [8]. Earlier ways of smart farming have been the use of manned aircraft for farm surveillance, spraying pesticides, and monitoring livestock. But then, hiring manned aircraft and a skilled agricultural pilot, which costs an average of $80,000 per year, is not a sustainable practice for many farmers [9]. Very recently, farming technology developers are looking forward to the use of unmanned air robots or drones as a measure to increase crop yields without negatively impacting the quality and quantity of production. Lately, agricultural drones have been introduced to pollinate date palms, overcoming the lack of mechanization indices in date palm cultivation, reducing revenue loss, and the need for skilled palm tree climbers. This technology is still in its infancy and has not reached the common man for use and deployment.

This paper analyses the impact of introducing drone technology into the date palm pollination process. The study reviews the results of autonomous pollination research in date palm trees conducted during the 2022 season in the orchards of Al Dahira Governorate, Sultanate of Oman. The benefits and challenges of aerial pollination techniques in date palm trees are discussed in the paper. The effect of this mode of pollination on fruiting traits such as yield, fruit quality, and FSP are explored. The paper is organized as follows: Section 2 provides the background of the study, Section 3 covers the literature review and Section 4 discusses the methodology of the investigation. Results and discussions are presented in section 5 followed by a conclusion in Section 6.

2. Background

Today's farmers are under much pressure to meet the current global needs in a fast-changing world where weather patterns are unpredictable, market prices are volatile, and pest issues and diseases are uncontrollable [10] Furthermore, the world's population that will reach 9 million by 2050 will lead to an increase in food demand by 70% and decrease in cultivable land [9]. In order to meet the demands of the future, the current agricultural practices need a makeover, in the sense of speeding up production, at the same time maintaining quality standards. Many contemporary methods of farming such as precession farming, organic farming, and bioengineering are being introduced into traditional agricultural practices in recent years. The 21st-century farmers need to be aware of the latest breakthroughs in science and technology and incorporate them into their farming practices. They are required to adapt to ever-changing world events to maximize production, reduce cost and improve efficiency [11]. This involves applying technologically sound and cost-effective practices to make effective decisions about growing crops, that will lead to better results in the shortest possible time. Nevertheless, the agricultural sector is still far behind in technological advancements in most parts of the world. More research is needed in this area to find out the applicability of emerging technologies for providing effective solutions to some of the existing challenges. Delivery of precise, reliable, and timely information to the main stakeholders of the agricultural industry is also a pressing priority.

The use of unmanned aerial vehicles or drones in farming has been in existence for the past few years and its usage in the agricultural industry is in the booming stage. Although this technology is still nascent, due to its abundant prospects, it is highly likely to improve farming practices and transform the agricultural industry across the globe. According to the latest research, the global agricultural drone market would grow at a 35.9% Compound Annual Growth Rate (CAGR) and reach $5.7 billion by 2025 [12]. Currently, drones have built-in sensors and data-gathering devices, literally providing an 'eye in the sky' for ranchers [13]. They can assist in pest monitoring, pesticide spraying, sensing soil moisture or dryness for regulating water supply, preparing for weather glitches, geo-fencing, etc. Countries, such as the United States, China, and Japan were the first to use drones in their agriculture sector. In the US, drones are used by grape farmers to increase their overall yield by surveying the farms and identifying infertile lands [14]. In China, farmers are using drones for crop spraying purposes for many years. In farms that have thin rows of crops and those with hilly terrains where tractors and ground vehicles are hard to reach, aerial application of water, fertilizers, and pesticides is highly advantageous. In Japan, unmanned helicopters are used for pesticide spraying rice, soybean, and wheat farms. 90 percent of the country's crop protection through pest control is achieved currently through the use of drones [14].

Using drones in a variety of applications in the farming process promises different benefits including accurate data collection, good return on investment, and improvement in quality and marketable quantity of yield. The well-known challenges that the farmers face are the high cost of investment to own a drone unless it can be hired for a specific time, airspace interference, flight time limitations, knowledge, and skill to operate the drone, and more importantly, privacy and policy issues. Most governments are working towards making and revising the regulations around drone use, to the technology easily available to farmers. Though there are many ways drones can be useful to ranchers, it is important to understand their limitations and functions before investing in such expensive equipment. More research is required to be done on their effectiveness in certain applications, such as pesticide application and spraying. Though drones are put to task in the agriculture industry including real-time crop monitoring, assessing crop stages, soil profile analysis, nutrient and irrigation management, etc., their use in the pollination process is still in its early stages. Drone use in the artificial cross-pollination of date palms is being tried recently in countries in the middle east. This paper is a summary of the results of a drone pollination research study project conducted in the orchards of Oman in the 2022 season on cultivars such as the Naghal, the Khanesi, the Fard, and the Khasab.

3. Literature Review

Unmanned aerial vehicles (UAV) or drones were used for military purposes years before electricity was invented. The first form of UAVs was reported in 1849 when Austria attacked the city of Venice with unmanned hot air balloons that were loaded with explosives [15]. At that time, remote piloting was hardly possible. The first pilotless winged aircraft remotely controlled with a radio mechanism similar to the drones of today was developed by Ruston Proctor Aerial Target in 1916 [16]. Since the first world war, UAVs have conventionally been used in military applications for reconnaissance purposes, as target practice drones and surveillance artillery [17]. The first non-military drones were deployed in 2006 by government agencies for disaster relief, wildfire fighting, border surveillance, pipeline inspection, and pesticide spraying on farms. In 2013, Amazon Company proclaimed its intention of using drones to deliver parcels generating interest in the usage of drones in civilian applications**.** These days, drones are increasingly being used in several industrial sectors including humanitarian relief and disaster management. In addition, it is now an emerging technology in the agricultural sector mainly for planning and data collection [18].

Currently, drones are considered a relatively new, less mature tool compared to the new technologies that are currently being applied in precision farming. The first UAVs in the farming sector were introduced in the 1980s for crop dusting. Over the years, the advancement of technology in the agricultural sector has made drones in use for the precise aerial application of pesticides and fertilizers over agricultural areas and aerial imaging to support both crop field mapping and growth monitoring [19]. As most agricultural applications are short endurance runs, a majority of the UAVs are gasoline or methanol-fueled, or battery-powered. Most modern drones use rechargeable batteries or are solar-powered which have long endurance capability [20].

In 1983, the Yamaha Motor Corporation in Japan developed the Remote-Controlled Aerial Spraying System (RCASS) to use drones for the aerial application of fertilizers. In 1990, they launched the R50UAS helicopter, which had a payload capacity of 44 lb, and in 1997, the unmanned helicopter, R-MAX was introduced. It was equipped with DGPS (Differential Global Positioning System) sensors by 2000 [21]. The R-MAX was used in a study conducted by the University of California on vineyards which compared the use of tractors and manual labor with UAVs. The results showed that the UAV could cover the area 10 times faster than the tractors could, though flight velocity was only 12 mph [14].

Remote sensing UAVs were used to assess crop growth and soil condition through variations in spectral responses. The information gathered from remote sensing helps to identify diseases, pest attacks, nutrient deficiencies, water status, growth of weeds, plant populations, and other damages [22]. They have lower operational costs and higher flying time. They are also safer to operate in lower altitudes and under extreme weather conditions. Meivel, et al. [23] reported that a quadcopter UAV, attached to a pesticide/fertilizer spraying system, allows farmers to access and apply pesticides/fertilizers in areas that are not easily accessible. Also, the multispectral cameras on the drones can help farmers capture remote sensing images and identify areas where the application is improper. In a study conducted by Mone, et al. [19]. The researchers articulate that an automatic spraying mechanism could be incorporated into the drone, to help farmers keep away from the harmful effects of some fertilizers. This also helps to ensure that an appropriate quantity of fertilizer is applied to the whole or parts of the farm. Modern drones used for surveillance of farms have built-in sensors that can measure specific wavelengths of light absorbed and emitted by plants. The problematic areas in the field are highlighted in the color-contrasted images generated by these sensors [24].

Drones to monitor plant diseases are tested and found successful in different parts of the world. In Sri Lanka, the eBee drone captures photosynthetic images which are capable of identifying the stress (pests or diseases) in plants and can warn the farmers 10 days before it becomes visible to the naked eye. Drones are being used in Virginia to recognize and destroy flying pathogens even before they land on the plants. Fengbo, et al. [25] also reported the use of drone-captured images that helps farmers to find out if their plants have been attacked by fungi or weeds, or other pests. Gupta et al. testified that drones with spectral and thermal imaging sensors can help farmers to identify the dry areas where watering is not uniform and can detect cracks and leaks in the pipes Gupta, et al. [26]. Lausch, et al. [27] stated that estimation of evapotranspiration in plants is possible using a drone with Red and NIR spectral filters and a temperature camera sensor [27]. The research also found that special monitoring equipment in the drone can detect areas experiencing an inadequate supply of sufficient water. With the help of these drones, the farmers will be able to calculate the vegetation index for better crop management. Soil moisture estimation using drones is still under research. ProHawk is a commercial drone in the market equipped with a sonic bird repeller, designed to scare the birds away with a sound system that mimics and sends predator sounds [28].

Unmanned Aerial Vehicles (UAVs) are becoming fairly affordable to the common man and governments are being more moderate on the laws and regulations of registration and operation of drones to ensure that drones are used to their fullest potential in farming activities. These changes resulted in the overall growth of drone technology [29]. While there is abundant information on the use and application of in the agricultural sector, the majority of this data is mainly either speculations that were not tried, tested, and published or few experimental projects in a specific farm; as the number of cases where drones are applied in farming sectors worldwide is limited. Also, the literature shows that while drones are applied in many areas of farming including plant growth monitoring, disease identification, pest control, fertilizer spraying, etc., their potential in the area of pollination is unexplored. This study evaluates the use of UAVs in the pollination of date palms based on an experiment conducted during the 2022 season in Oman.

4. Methodology

The aim of the research was to perform an artificial pollination experiment on 50 female date palm trees using liquid suspension pollen sprays via drones. The study was implemented during the 2022 flowering season in an orchard of 30 ha in Dhank (23°33'10.0"N, 56°16'00.5"E) in the Al Dahira Governorate of Oman. The field was organically manured and the irrigation system was by 'falaj'(a water channel system that evenly divides water between farms). Most private farms in Oman do not grow date palms of the same cultivar, but a combination of different cultivars. Palms in the identified farm were derived mainly from four cultivars namely, the Naghal cultivar of 10 years of age and vigor, and the number of leaves per bunch was around six; the Khanezi cultivar of 14 years of age and vigor, with approximate eight leaves per bunch; the Fard cultivar of 8 years of age and vigor, and the number of leaves per bunch was approximately seven and the Khasab cultivar of 10 years of age and vigor, with an average of five leaves per bunch. Palms were planted in rows at a 10 × 10 m distance between the plants. Fifty trees from all four cultivars (12 trees each from cultivars Naghal, Khanezi, and Khasab, and 14 trees from cultivar Fard) were used as female parents. The DPP (date palm pollen) was prepared by a specific formula in liquid form. Liquid spraying of pollens was found to have optimal results based on the manual pollination studies conducted by the authors in the earlier seasons [6]. Male inflorescences were collected from one male palm tree, commonly known as Fahl (15 years of age and vigor). The male flowers were dried and pollen dust was extracted which was stored at 4 °C in the refrigerator until each female palm was ready for pollination. The required amount of DPP dust is converted to liquid form just before spraying as it is not advisable to store liquid pollens due to the chances of losing their vigor. The liquid pollen suspension was made by mixing extracted dry pollen with water, in combination with boric acid, a germination stimulant. This method requires only low proportions of DPP per liter of water (4 g pollen/L water).

Mainly, two types of drones are used in the agricultural sector; medium-sized ones which are principally used for surveillance, data collection, and analysis, and larger drones which are used for planting and spraying pesticides/fertilizers. In this study, for aerial pollination, the UAV chosen was the agricultural drone DJI AGRAS T20 which is shown in Figure 1. It is a hexacopter with a total weight of 21.1 Kg (excluding battery) with a 20 L spray tank and can autonomously operate over a variety of terrains. The hovering time is 10 minutes with an 18000 mAh battery (Figure 2), at the maximum take of weight 47.5 Kg. They can fly at a maximum speed of up to 22.36 miles per hour and are limited to an altitude of 500 feet. The spraying system has 8 nozzles with a maximum spray rate of 3.6 L/ minute. The drone has an in-built real-time visual monitoring system and omnidirectional digital radar for obstacle avoidance. These systems enable the drone operator to easily regulate their altitudes and change the flight paths in accordance with the topography of the terrain. For autonomous pollination, the area of pollination can be mapped out and this 3D data collected from the map may be fed into the pollination algorithm using which the drones autonomously pollinate the trees. For operator-assisted pollination, the aerial view from the drone can be captured by the FPV camera in the drone at a resolution of 1280×960 30fps which provides sufficient information to the operator regarding the target location.

Figure 1.
DJI AGRAS T20 (Courtesy: Wakantech Oman).

Figure 2.
18000 mAh rechargeable battery.

Figure 3.
Filling liquid pollen suspension in the tank of AGRAS T20**.**

When the flowers become receptive, it is time for pollination. The DPP dust already extracted and stored is mixed with water and germinating agent and filled in the tank attached to the drone as shown in Figure 3. Dry pollens in their pure state are normally difficult to dissolve in water and so suitable solubilizing agents may be used if necessary. Research is still underway and trials are being conducted to identify suitable solubilizing agents that do not pose a threat to the viability of the pollens. In this study, no such catalysts were used. An important point to be noted is that the pollination time of each tree in the farms may vary based on the maturity of the female flowers. So drone sprinkling of pollens may have to be done multiple times in limited quantities to ensure sound pollination. The process of spraying liquid suspension pollen on the inflorescences of a tall date palm tree in the orchard is shown in Figure 4.

Figure 4.
Drone pollination is being done on a tall date palm tree.

The time taken to pollinate each inflorescence is from 4 seconds to 20 seconds, which means that the entire farm of 50 trees can be pollinated in less than 15 minutes. This was well within the battery capacity of the drone. For larger farms, the drone may have to be brought down more than once to replace/recharge the battery or refill the tank. In this experiment, approximately 700 ml of liquid pollen was disseminated for each tree in one round and the process was repeated one more time after 4 days. Pollination was done first for the 12 Naghal palms whose flowers become receptive in the earliest period of the season by January, after which the Khanezi palms were treated (in February) and Khasab and Fard palms were pollinated in March 2022.

5. Results and Discussion

The fruits of the Naghal started to mature in June 2022, followed by Khanezi in July and Khasab and Fard in August 2022. In the "Rutub"(fresh dates) stage, the Naghal is a long golden yellow textured fruit with sweet juicy flesh. The rutub of khanezi is light wine red with a more oval-shaped fruit. "Rutub" (fresh dates) harvested from the Naghal and Khanezi cultivars is shown in Figure 5. Liquid suspension at the concentration of 4.0 g/l gave a considerable fruit set percentage (FSP) of 60.32% for the Naghal Cultivar and 66.54% for the Khanezi cultivar on average.

Figure 5.
Ratab from Naghal (Left), Ratab from Khanezi (Right).

The average FSP in Naghal for the tall trees was significantly higher, (around 64.68%) than that for short ones (around 56.24%). The same trend is seen in the cultivar Khanezi, 69.74 % and 61.29% for tall and short palms respectively. However, bunches in shorter palms with lower fruit sets had a higher proportion of large-sized fruit. In addition, the fruit quality in both tall and short palms remained unaffected. The reason for reduced fruit sets in short palms is that the dispersal of pollens in short palm inflorescences was not adequate via drone spraying due to the inability of the drones to reach closer to the targeted inflorescences in short trees that have grown in between the tall ones. The fruit development in tall and short palms is depicted in Figure 6. The average FSPs in the cultivars Khasab and Fard, for the same concentration of liquid DPP, are seen as 59.63% and 61.28% respectively. The trend for tall and short palm trees is the same (higher for tall and lower for short) in both cultivars as well.

Figure 6.
Fruit development in tall (left) and short palms (right).

The amount of liquid suspension used for one round of drone spraying was 35 liters. The total DPP consumed at a concentration of 4g pollen per liter of water was 140g. This represents a male/female ratio of 1 to 50. In other words, one male palm can pollinate up to 50 female palms, having 16 to 18 inflorescences on average via spray pollination method using drones.

5.1. Benefits of Drone Pollination in Date Palms

The number one advantage of drone pollination in date palms is that the method is exceptionally faster. It is seen that manual pollination of one tall palm tree usually takes 20 - 30 minutes. This means that in a farm of around 50 trees it would take 20 to 25 hours to complete the pollination process. Focusing on drone technology to pollinate date palms can significantly save pollination time as it takes as low as 4 seconds to 20 seconds to pollinate one palm tree. The entire farm could be covered in 30 minutes. This implies an improvement factor of around 96% to 99% in the overall pollination time. In short, drones have the ability to scan many farms in a few hours.

In addition to the speed advantage, the drones carry GPS (Global Positioning System), HD (High-Definition) Camera, and other data collection devices that help in analysis and subsequent crop management. A combination of remote sensing, image processing, data analytics, machine learning, industrial design, etc., helps to improve the efficacy of date orcharding significantly. The specifications of these in-built systems can be customized and enhanced as per requirements to improve farming efficiency further. The method significantly reduces the amount of physical labor required for pollinating date trees and in turn reduces the cost of labor involved in manual pollination. It is also seen that there is no noteworthy difference in the quality and quantity of fruits produced compared to the traditional method of pollination. Rather, the productivity of tall date palms has improved considerably.

In summary, the compact size, fair cost, and handy design of drones have made them fundamental convenient tools that can be used in a variety of agricultural applications including the pollination process. However, it is important to note that drones have many advantages over the existing expertise, among which are low operation costs, maneuverability, speed, safety, and accuracy.

5.2. Challenges of Drone Pollination in Date Palms

Although there are many notable advantages of using drones for the pollination of date palms, one must consider the following factors before deciding to use the technology in their farms.

The drones are not capable of accessing the inflorescences of short trees growing in between the tall ones due to the presence of thorny thick leaves around the female flowers. Effective pollination on short palms in closely packed plantations using drones is a challenge. Neither sufficient quantity of pollens reaches the inflorescences nor is spread evenly on them. The results show significantly lower FSP and a higher presence of parthenocarpic fruits in shorter palm trees compared to taller ones. A suggestive solution to this problem is to overcome the inaccessibility by redesigning the spraying module attached to the drone to reach the targeted location. A custom-made pollen dispenser that can identify the flower arms and shoot themselves out to reach the inflorescence and precisely dispense pollen to the target location is a proposition by the authors to address this challenge. Also, aerial pollination at a specific height not only pollinates the targeted palm trees but also affects the pollination process of neighboring farms. There can be a consequence of wastage of pollen leading to environmental pollution as well. The concern is more severe when dry pollen dusts are dispersed via drones. The pollen dispenser with a robotic arm to reach the specific inflorescence and controlled spraying of liquid pollens in the targeted area would help to curb this problem to some extent.

Drones carrying pollen containers of higher capacity (30l or more) reduce flying time due to higher power consumption. In larger farms, this can be a challenge as it may have to be brought down multiple times to change or recharge the battery. The drawback with smaller tank sizes is that the drones need to land many times, before completing the task, to refill the tank.

Currently, the commercial use of drones, in many countries including Oman, is highly regulated. A certified pilot is only allowed to fly drones. Civilians are not given permits and licenses to fly or own them. Not every farmer can purchase a drone in Oman. It requires special permission from ROP (Royal Oman Police) and a purchase a license to buy a drone. This is in view of the fact that drones not only infringe on the privacy of people but also comprises on their safety, if not handled properly. Civil authorities have curtailed the commercial use of drones in most parts of the world, mainly because of their historical use in the military. Though drone-related accidents are not reported so far, studies conducted by the University of Dayton reveal that drones can cause major damage to a manned aircraft and can lead to a crash [30]. Though authorities are in the process of relaxing the policies to make the technology available to the ranchers, many farmers lack the funds to invest in these devices which have not yet been fully tested for their effectiveness and reliability. The other alternative is to lease/rent an agricultural drone of the required specifications along with a certified pilot, from a licensed smart farming technology developer or company, for a short period.

6. Conclusion

The purpose of this study is to provide future readers with a better understanding of the impact of drones in the agricultural sector, specifically in the pollination process of date palms. The paper also expects to assist related policymakers and agricultural educationists to develop and/or amend appropriate guidelines and regulations for the use of drones in precision farming. Experimental studies conducted during the 2022 season of date palm pollination in Oman show that the incorporation of this innovative method of pollination using drones has a speed and cost advantage without compromising on the yield, fruit quality, and FSP. The major limitations of this technology in the pollination process are summarized and possible solutions are suggested. Although its usage is constrained, it is, however, a revolutionary step in the agricultural sector, providing immense employment opportunities to the youth and enhancing the awareness of the farmers. In view of the demands of the growing population, the farmer’s needs, operational regulations, and shrinking agricultural lands, such ground-breaking initiatives are highly encouraging, though major reforms in the technology are anticipated in the future to address the challenges raised.

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