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[F] PhD Extended Abstract Form

INVESTIGATION ON THE SPRAY CHARACTERISTICS OF AUTONOMOUS DRONE SPRAYER AND DESIGN AND DEVELOPMENT OF AERIAL CENTRIFUGAL SEED AND FERTILIZER BROADCASTER

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Extended Abstract

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1. Introduction

Pesticides application

Application of pesticides plays an important role in controlling the pest in agriculture. Proper application of pesticide and selection of equipment used for applying pesticide are important for successful pest management. In the present context small scale farmers are using knapsack sprayers. These sprayers are either manual operated or battery operated which are to be carried by the operator for spraying which causes drudgery and there is often leak, which causes the drenching of skin and clothing with pesticides causing health hazards. Furthermore, it increases the fatigue of operator if used for longer period.

Drone technology for crop spraying

In order to reduce human intervention in spraying operations, autonomous drone is an emerging technology in the field of agriculture. It solve the issues of effective pesticide spraying in a larger area thereby achieving timeliness of operation while reducing labour requirements and human drudgery.

In recent times, multi-rotor drones have become progressively important in the field of crop spraying against diseases, pests, and weeds. Drone sprayer with easy take-off and landing systems, hovering capabilities, and high spraying efficiency are essentially needed to spray pesticides for crops in a timely and effective manner, especially in dispersed plots and hilly terrain. The most essential benefit of using a drone (multi-rotor) for chemical spraying is that, due to its unique rotor structure and principle of motion, it generates powerful downwash airflow during flight operation, changing the crop canopy and improving liquid penetration.

Research problem and Justification

There is no detailed study in India regarding performance of machine operational parameters viz., height of spray, travel speed, discharge rate, type of nozzles and spacing, spray droplet characteristics and application rate for different crops. Commercial drone manufacturers are adopting drones without having basic information on the performance and efficacy of the drone spraying system in terms of pest control. To address this issue, there was a need to investigation on the spray characteristics of autonomous drone sprayer and design and development of aerial centrifugal seed and fertilizer broadcaster. Hence, keeping in the view above mentioned facts, study was undertaken with the following specific objectives

1. To study and selection of commercially available agricultural spraying drones in India
2. To study and optimize the machine and operational parameters of drone sprayer in the laboratory
3. To evaluate the performance of drone sprayer for selected field crops
4. To design, develop and optimize the machine and operational parameters of centrifugal seed and fertilizer broadcaster as an attachment to drone
5. To evaluate the performance of aerial centrifugal seed and fertilizer broadcaster in field condition.

2. Review of literature

The current aerial spray application research is primarily focused on examining the influence of drone spraying parameters such as flight height, travel speed, rotor configuration, droplet size, payload and wind velocity on droplet deposition. These spray operational of the selected drone sprayer model, have a great impact on the distribution and penetration of droplets due to the strongly positive relations between downwash airflow velocity and droplets. Therefore, the uniformity of the spray should be assessed in order to provide a good deposition uniformly over the whole height of the crop canopy. Many investigators have carried out research on the spray effects of drone spray technology. Even now, traditional method of spreading seed and fertilizer with hands is being followed, these operations are more laborious, time-consuming, lack of uniformity and hazardous to health. In order to overcome this situation, additional attachment to the autonomous drone for the application of seed and granular fertilizer was developed which can reduce labour, ensure uniform spread of seed and fertilizers. Most importantly, drone based centrifugal broadcaster reduces the threat to the operator's health. An attempt was made to adopt the six-rotor drone sprayer for aerial centrifugal seed and granular fertilizer broadcasting.

3. Materials and Methods

3.1 Study on downwash airflow pattern of drone sprayer in the laboratory

The downwash airflow velocity generated by the drone rotor propeller has a significant impact on the droplet deposition process. A test rig was developed to measure the downwash airflow pattern generated by the rotor propeller of a drone sprayer. In this investigation, a six-rotor electric autonomous drone sprayer was used to investigate the parameters and distribution laws of downwash airflow velocity. The downwash airflow velocity was measured using portable anemometers mounted on the test rig at radial positions viz., 0 m, 0.5 m, 1 m, 1.5 m and 2 m, perpendicular to (X) and parallel to the drone sprayer flight direction (Y). The experiment was conducted at three levels of hover height, viz., 1 m, 2 m and 3 m (Z) and three levels of payload, viz., 0 kg, 5 kg, and 10 kg. The special downwash airflow distribution pattern was analysed using the Python programming language (Version 3.7).

3.2 Study and optimize the spray operational parameters and spray volume distribution pattern of drone sprayer

The present study aimed to study and optimize the effect of spray height, operating pressure, nozzle spacing and spray nozzle mounting configuration on spray discharge rate, spray width, spray distribution pattern, spray uniformity and spray liquid loss. A spray patternator of 5.0 m x 5.0 m was developed per Bureau of Indian Standards (BIS) standard to study the spray volume distribution pattern of boom and hex nozzle configuration nozzle configuration. Initially, drone spray operational parameters viz., spray discharge rate (l m^{-1}), operating pressure (kg cm^{-2}) and spray angle (º) were measured using digital nozzle tester, digital pressure gauge and digital protractor respectively in the laboratory. Then optimized the nozzle spacing for boom configuration attachment to drone sprayer and recorded best spray uniformity at 0.6 m nozzle spacing. The drone sprayer hovered at three different heights, viz., 1.0, 2.0 and 3.0 m from the top of the patternator and spray operating pressure was maintained at 4.0 kg cm^{-2} in outdoor condition. Single pass distribution pattern and one-direction application distribution pattern method used for optimizing drone sprayer operational parameters *viz.,* height of spray (m), operating pressure (kg cm^{-2}) and nozzle mounting confirmation (boom and hexa) from the results of discharge rate (l m^{-1}), spray angle (º), effective spray width (m), spray liquid loss (ml) and spray distribution uniformity (%).

3.3 Study on spray deposition and drift characteristics for application of Insecticide in the field condition

One of the important machine parameters influencing droplet deposition and drift characteristics in UAV sprayers is downwash airflow generated by a multi-rotor propeller. A field experiment was carried out at the redgram research field (N11.01, E76.92), Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, during 2021–2022 to study the spray drift and deposition characteristics of an autonomous UAV sprayer. The Imidacloprid (a.i. 17.8SL) insecticide mixed with water in a ratio of 1 mL per liter was sprayed with a UAV sprayer. Water-sensitive paper samples were kept at upper, middle, and bottom positions on the leaves, and data were analyzed for the spray droplet size, deposition rate, droplet density, and area coverage both in target and non-target areas using Spray Deposit Scanner software.

3.4 Effect of downwash airflow distribution of multi-rotor unmanned aerial vehicle on spray droplet deposition characteristics in rice crop

The UAV downwash airflow pattern generated by rotor propellers is one of the significant factors influencing the characteristics of spray droplet deposition distribution. UAV sprayer and battery operated sprayer were used to study the effect of downwash airflow distribution of UAV on spray droplet deposition characteristics in a paddy field. The UAV sprayer was operated with optimized operational parameters and spray droplet characteristics, viz. spray deposition rate (µl cm^{-2}), spray droplet size (µm), spray deposition density (No's cm^{-2}) and spray deposition uniformity (%) were analysed using USDA Deposit Scan software.

3.5 Design, develop and optimize the machine and operational parameters of centrifugal seed and fertilizer broadcaster as an attachment to drone

An attempt has been made in this study to design and develop a centrifugal broadcaster attachment to drone to spread the seed and granular fertilizer at a desired rate. Hopper was designed by considering the payload 10 kg and 7.5 kg capacity of urea and paddy, respectively. A trapezoidal shape of 220x220x350 mm size hopper tank was fabricated with light aluminium sheet materials to provide stability for the aerial broadcaster. Provision is made for sliding mechanism attachment to the hopper and support frame for easy filling of urea and paddy. Optimization of machine and operational parameters of aerial broadcaster was done in laboratory condition.

3.6 Performance Evaluation of aerial centrifugal seed and fertilizer broadcaster in field condition.

The performance test of developed aerial centrifugal broadcaster for application of paddy seeds, urea fertilizer and manure seeds (dhaincha and sunnhemp) were carried out at Wetland, Tamil Nadu Agricultural University, Coimbatore. The optimized machine operational parameters were fed to match the required application rate of paddy seeds (Direct sowing: 100 kg ha^{-1}), urea fertilizer (80 kg ha^{-1}) and manure seeds (kg ha^{-1})as per the package practice guidelines for autonomous aerial broadcasting operation.

4. Results and Discussion

4.1 Study on downwash airflow pattern of drone sprayer in the laboratory

Results show that the downwash airflow velocity generated by the radial position of the UAV rotor is evenly distributed on the rotating loop and the standard deviation of the downwash airflow velocity is less than 0.5 ms^{-1}. The maximum downwash airflow velocity of 13.8 ms^{-1} was observed below the rotor at 10 kg payload capacity, 1 m hover height (Z), and 0.5 m in the X-direction. The minimum downwash wind field of 0.3 ms^{-1} was observed at 0 kg pay load capacity, 1 m height, and 2 m in the X-direction. The downwash airflow velocity along each position in the radial direction of the rotor increases initially and then decreases. This downwash airflow distribution results helps in mounting of spray nozzle configuration to drone sprayer which helps to understanding spray liquid distribution and other spray operational parameters. The influence of downwash airflow distribution combined with the spray operational parameters of the UAV sprayer viz., flight height, travel speed, rotor configuration, payload and wind velocity on spray volume distribution was studied.

4.2 Study and optimize the spray operational parameters and spray volume distribution pattern of drone sprayer

Results showed that, the better spray uniformity distribution was found when the drone sprayer hover height was increased from the top of the patternator (2.0 m). More round spray droplet vertex pattern was generated during the 1.0 m hover height compared to the 2.0 and 3.0 m hover heights due to the direct impact of downwash airflow generated by the rotors. Lower volume of spray was collected at the middle portion, when the drone was hovered at 1.0 m height due to the direct impact of downwash airflow of rotors. Finally it was concluded that, the good spray volume distribution was found at 2.0 m height of spray with standard hexa nozzle configuration arrangement as compared to the boom spray nozzle arrangement.

4.3 Study on spray deposition and drift characteristics for application of Insecticide in the field condition

Overall, the droplet deposition rate (2.47 µL cm^{-2}), droplet density (51.00 droplets cm^{-2}), and area coverage (15.77%) were highest in the upper layer as compared to middle layers (0.75 µL cm^{-2}, 19.33 droplets cm^{-2}, 10.25%, respectively) and bottom layers (0.37 µL cm^{-2}, 19.00 droplets cm^{-2}, 2.73%, respectively). The droplet penetrability was best in the upper layer, with the CV of deposition density reaching 6.34% and 13.02%, respectvely). Spray droplet is one of the most critical aspects affecting the droplet deposition rate, area coverage, and droplet density for insecticide spraying by UAV in the redgram field. There was higher droplet deposition rate (1.79 µL cm^{-2}), area coverage (16.17%) and droplet density (48.00 droplets cm^{-2}) in the target area as compared to the non-target area (deposition rate: 0.39 µL cm^{-2}, coverage: 3.54% and droplet density: 10.00 droplets cm^{-2} respectively), which may have been due to the downwash air produced by the propeller of the UAV sprayer. The downwash air velocity had effects on droplet deposition and the standing crop. Droplet deposition rate decreased as the lateral distance from the center of the UAV spray line increased (from 1.93 ± 0.05 µL cm^{-2} to 0.22 ± 0.05 µL cm^{-2}), and similarly, the spray droplet drift distance was reduced with the increase in droplet size, which showed that the increase in spray droplet size can effectively minimize the spray droplet drift.

4.4 Effect of downwash airflow distribution of multi-rotor unmanned aerial vehicle on spray droplet deposition characteristics in rice crop

The drone spray method helps in uniform coverage per unit area in the upper and bottom layers of 8.83 % and 8.36 %, respectively compared to manual spray method in upper and bottom layer as 10.30% and 2.86%, respectively. The average droplet deposition densities on the upper and lower layers are 36.66 and 30.66 droplets cm^{-2} respectively, for the drone sprayer and 41.00 and 13.00 droplets cm^{-2}, respectively, for the knapsack sprayer. Thus, drone spray method gave better and uniform droplet deposition densities compared to manual knapsack sprayer. The deposition uniformity was better in the upper and bottom layer with the relatively smaller values of coefficient variation value 4.2% and 8.2 % respectively using drone sprayer compared to knapsack sprayer with uneven deposition uniformity in upper and bottom layer 8.0 and 14.8 % respectively. Uniform droplet distribution deposition rate and area coverage were found with the use of the drone sprayer as compared to the knapsack sprayer. This may be due to downwash air produced by the propeller of the drone sprayer having a great influence on spray droplet deposition.

4.5 Design, develop and optimize the machine and operational parameters of centrifugal seed and fertilizer broadcaster as an attachment to drone

Optimization of broadcaster disc speed was done by spread pattern test for broadcasting of paddy seed and urea fertilizer. It was observed that, there was better uniformity of distribution when the rotational speed of disc increased from 400 to 800 rpm. The aerial centrifugal broadcaster was operated for three forward travel speed viz., 2.0, 3.0 and 4.0 m.s^{-1} and three broadcaster exposure length viz., 8, 10 and 12 mm, respectively. Deposition rate, and application rate of paddy seeds and urea fertilizer were calculated. The effective spread width was found as 1.9 m when uniformity of paddy seed distribution was 8.0% during 10 mm broadcaster exposure length at 2 ms-1 travel speed in one-direction application distribution pattern.

4.6 Performance Evaluation of aerial centrifugal seed and fertilizer broadcaster in field condition.

The aerial application of actual quantity of paddy seed applied was 20 kg for 0.5 acre (100 kg ha^{-1}) using aerial centrifugal broadcaster. The plant population per meter square was measured as 356 No.s per square meter and there was uniform paddy seed population as 15.34 % as compared to manual method 21.84 %. The aerial application of actual quantity of urea fertilizer in paddy field applied was 17 kg for 0.5 acre (80 kg ha^{-1}) using aerial centrifugal broadcaster.

In aerial application of manure seed experiment, plant population per meter square was measured as 45.37 No.s per square meter and there was uniform seedling manure seed population as 16.65 % as compared to manual method 22.33 %. The aerial application of actual quantity of sunnhemp manure seed applied was 15 kg for 1.0 acre (36 kg ha^{-1}). The plant population per meter square was measured as 61.20 No.s per square meter and there was uniform seedling manure seedling population as 21.93 % as compared to manual method 27.18 %.

5. Conclusions

The optimum spray height was 2.0 m, in which the downwash air flow has a better effect on spray volume distribution. The drone sprayer should be operated at an appropriate spray height of 2.0 m to attain the recommended application rate of pesticide. Droplet deposition rate decreased as the lateral distance from the center of the UAV spray line increased (from 1.93 ± 0.05 μL cm^{-2} to 0.22 ± 0.05 μL cm^{-2}), andsimilarly, the spray droplet drift distance was reduced with the increase in droplet size, which showed that the increase in spray droplet size can effectively minimize the spray droplet drift. The UAV spray method is quite effective, not only in terms of reach but also in mitigating health risks faced by farmers who walk through the fields with handheld sprayers, exposing themselves to toxic chemicals. Moreover, it will help to overcome the shortage of labor. Drone multi-rotor downwash airflow had a great impact on the spray droplet deposit rate in the rice crop, which will be useful for fighting stem borers, which are usually present in the lowest part of the plant. Design and developed the functional components of aerial broadcaster attachment to drone sprayer. Then optimized the machine and operational parameters of aerial broadcaster for paddy, green manuring seeds and urea fertilizer application at laboratory condition. Then finally evaluated its performance in field condition for application of paddy seeds, urea fertilizer and manure seeds and showed better results compared to the conventional method with frames.

Final remarks concerning benchmarks and strength points of the the Pellizzi Prize 2024

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In this investigation, a six-rotor battery operated autonomous drone spraye operational parameters *viz.,* height of spray (m), operating pressure (kg cm^{-2}) and nozzle mounting confirmation (boom and hexa), discharge rate (l m^{-1}), spray angle (º), effective spray width (m), spray liquid loss (ml) and spray distribution uniformity (%) were optimized. Field experiments were conducted in redgram and rice crop to study the spray droplet deposition characteristics. The selected drone sprayer was modified for the application seed and granular fertilizer. Then optimized the machine and operational parameters of aerial broadcaster for paddy, green manuring seeds and urea fertilizer application at laboratory condition. Then finally evaluated its performance in field condition for application of paddy seeds, urea fertilizer and manure seeds and showed better results compared to the conventional method with frames. This modified drone unit for other operations *viz.,* seed and granular fertilizer distribution systems enables farmers to carry out three operations (spraying, seeding, and granular fertilizer application) with a single autonomous aerial vehicle, thereby increasing the productivity and income of the farmers. The cost of operation can be reduced and timeliness of operation could be achieved. A single unit can perform all three operations, which would increase the utilization of the equipment.

These research results of optimized machine and spray operational parameters of autonomous drone sprayer helps and references to the farmers, researchers, startups entrepreneur, policy makers for usage of drone spray technology in agriculture production. This autonomous drone spraying technologies are beginning to emerge as an incredible solution for many of the challenges we have today in the industry. Agriculture is one that we have to really take into account and analyze.