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Assessment of on Field Droplet Distribution through Unmanned Arial Vehicle (UAV) Spraying for Potato Crop in Hills of Uttarakhand

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ABSTRACT: Maximizing crop yield and minimizing input costs can be achieved through the judicious application of insecticides, pesticides, and fertilizers. The field experiment was conducted at farmer's field at village Museti (Location I) and Kaparoli (Location II), District Pauri Garhwal, Uttarakhand to investigate on field droplet distribution through Unmanned Arial Vehicle (UAV) spraying for potato crop. The UAV sprayer is used to analyze the droplet distribution at different height (2m, 3m, 4m) and different speed (1 m/s, 3 m/s, 5 m/s). The planning was made for distribution of droplets evenly at upper middle and lower part of the plant. For potato crops, the Volume Median Diameter (VMD) of spray droplets was observed to increase with greater flight height and decrease with higher flight speed. A similar trend was noted for the Number Median Diameter (NMD). The droplet size (VMD) for potato applications ranged from 153.573 to 341.767 µm, while the NMD varied from 32.581 to 92.00 µm. Conversely, droplet density decreased as both flight height and flight speed increased, with observed densities ranging from 190.670 to 340.630 droplets/cm².

Keywords: UAV, Droplet distribution, Volume Median Diameter, Number Median Diameter, Droplet Density.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a vital crop globally, and in the hills of Uttarakhand, it has historically been a significant staple. However, recent years have seen a drastic decline in potato production in the region, with yields plummeting in just five years (2020-2024), largely due to erratic weather patterns, reduced snowfall, and rising temperatures. Traditional manual methods of applying fertilizers, insecticides, and pesticides in the challenging, fragmented, and steep terrains of the Himalayan foothills are inefficient, labor-intensive, and often lead to uneven distribution and exposure risks for farmers. Unmanned Aerial Vehicles (UAVs), or drones, present a transformative solution, offering precision spraying capabilities that can overcome these topographical constraints and ensure targeted application of agrochemicals and nutrients. This research explores the efficacy and feasibility of UAVs for crop protection and nutrient management in potato cultivation in the Uttarakhand hills, aiming to address the limitations of conventional spraying and contribute to sustainable agricultural practices in the region (Arya and Joshi 2019).

Conventional method of spraying (hand operated spraying) results in excessive application of chemicals and are difficult in orchard, paddy, dense crop field which leads to environmental pollution and less uniformity which further leads to more production cost. The drones are attached with the spray tanks which can store the pesticide and spray over the crop. These drones fly at a proper height, helping the pesticide penetrate perfectly into the fields. This way the effect of the pesticide is also highly effective as the chemical could now reach on the plant parts where it is not possible in case of manual spraying.

Due to their efficacy in field work, agricultural drones are becoming an option for modern farmers. When market demand for food is high, customers realize they must reconsider how to boost agricultural production and efficiency to directly affect the success of their farming enterprise. To determine which elements required improvement, soil quality, rainfall patterns, temperature, climatic change, wind speed, and the presence of weeds and insects were evaluated (Lee *et al.*, 2021). Currently, consumers prefer the usage of precision variable spraying systems mounted on unmanned aerial vehicle (UAV)-based sprayers over ground plant protection vehicles due to their speed of operation. Farmers are beginning to consider limiting the use of pesticides and regulating the environment to preserve the nutrient content of their land, in light of the high speed of drone operations. As researchers, we must also introduce public innovations that meet the demands of farmers (Morley *et al*., 2017). Moreover, by the end of 2020, the adoption of pesticide spraying technology that is high in efficiency, product safety, resource efficiency, and environmental friendliness will be promoted, with the ultimate objective of attaining a zero percent growth in overall pesticide use. The application of pesticides by unmanned aerial vehicles (UAVs) can limit chemical waste to precise levels. However, due to external factors such as wind and the effect of the UAV itself, such as fluid dynamics caused by propeller blowing, UAVs experience droplet drift and adhesion, resulting in non-uniform spraying (Lou *et al.,* 2018). The droplet size was significantly small in T3 (200.34 to 253.01 µm) compared to T2 (463.88 to 738.80 µm). The droplet density was significantly more in T3 compared to T2 at top, middle and bottom of the crop canopy. The maximum reduction in whitefly *Bemisia tabaci* (Genn.) incidence was observed three days after spray in T3 (36.84 and 42.72%) and T2 (28.71 and 29.70%) (Parmar *et al.*, 2022). The cone nozzle produced a spray that was uniform and had the lowest coefficient of variation at all pressures and heights tested. Using this model, for the cone nozzle, best spray volumetric distribution and the lowest coefficient of variation may be achieved as long as the nozzle pressure is 8 kg/cm^2 at 54.46° and the height is 600mm. We employed a flat fan nozzle at a 62.24° nozzle angle, 600 mm height, and a pressure of 6 kg/cm^2 to get the optimum spray volumetric distribution and the lowest coefficient of variation (Kailashkumar *et al.,* 2023).

Unmanned aerial vehicle (UAV) variable-rate spraying offers a precise and adaptable alternative strategy for overcoming these challenges. Future research is incentivized to continue the precision performance of the variable rate development by combining it with cropland mapping to determine the need for pesticides, although strict limits on the amount of spraying make it difficult to achieve the same, even though the quality is very beneficial (Hanif *et al*., 2022). Drones can deliver payloads, acquire real-time data in an efficient and cost-effective manner, and have been a driving force behind the rapid development of a wide variety of industrial, commercial, and recreational applications (Jayanth & Yadav 2023). The UAV sprayer was evaluated in a cotton field at 3 levels of flight height (1.5, 2.0, 2.5 m) and flight speeds (4.0, 4.5, 5.0 m/s) for effective spray distribution. The optimized operational parameters of flight speed of 4.0 m/s and flight height of 1.5 m were suggested by Design expert. The UAV was capable of spraying the liquid at the top, middle, and bottom positions of leaves satisfactorily. The VMD observed to increase with an increase in flight height and a decrease in flight speed. A similar trend was observed for NMD also. The droplet size (VMD) of cotton crop varied from 444 to 353.11 µm, and NMD varied from 49.33 to 95 µm. The droplet density decreases as flight height and flight speed increase, and the droplet density varied from 198.22 to 353.33 droplets/cm^2 (Ingle *et al*., 2024). Previous research has extensively examined how UAV working parameters impact droplet deposition and biological efficacy. The significant growth of UAVs in plant protection is largely attributed to their high efficiency and capacity to rapidly address issues like plant diseases and insect infestations with low risk. However, a critical gap remains: there is less reported evaluation of UAV working efficiency as a key performance indicator for plant protection. As an emerging technology, UAV spraying still faces practical challenges, including ensuring uniform droplet distribution, achieving adequate droplet coverage, improving pesticide penetrability into the crop canopy, and optimizing overall working efficiency.

MATERIAL AND METHODS

Field experiment was conducted at villages (Museti and Kaparoli), and College of Horticulture, Veer Chandra Singh Garhwali Uttarakhand University of Horticulture and Forestry, Bharsar, Pauri Garhwal during Kharif Season of year 2024. The geographical location of villages ranges between 30.0253° N latitude and 79.0116° E longitude, with an elevation of 1800 metres to 2100 metres above mean sea level. During spraying operation, the different meteorological parameters such as wind velocity, air temperature, humidity and rainfall which affects the quality of spraying. Therefore, during spraying operation meteorological parameters are noted in order to avoid the ill effects of climate on the performance of the sprayer. Crop parameters mainly influence the spraying techniques adopted for the field trials. The biometric crop parameters include type of crop, variety, stage of crop, row to row spacing, plant to plant spacing, leaf area index and date of sowing.

The UAV sprayer is used to analyze the droplet distribution at different height (2m, 3m, 4m) and different speed (1 m/s, 3 m/s, 5 m/s). To measure droplet deposition, glossy papers were strategically affixed to plant leaves at three distinct zones: Upper, Middle, and Lower. A blue dye was mixed with water to create a colored spray solution. After spraying, the collected glossy papers were sorted according to their respective zones. The colored spray solution left droplet traces on these papers, which were then analyzed using a droplet analysis system. This system, utilizing specialized droplet analyzer software, determined key parameters including droplet size, droplet density, and uniformity coefficient, as well as the total number of droplets and their area (Parmar, 2019). All the experiments replicated thrice for each treatment.

RESULTS AND DISCUSSION

The spraying through Unmanned Aerial Vehicle (UAV) was done on potato crops. The effect of variable height and varial speed mentioned in the experiment was studied for the pupose of eatcimation of Volume Median Diameter (VMD), Number Median Diameter (NMD), Uniformity coefficient (UC), and droplet density were studied.

A. Volume Median Diameter (VMD)

Droplet size is represented by volume median diameter (VMD). It is volume median diameter which is representative sample of droplets of spray on glossy paper which divide spray into two equal parts so that one half of the volume contains droplets smaller than a droplet whose diameter is the VMD and the other half of the volume contains larger droplets.

Table 1 illustrates the Volume Median Diameter (VMD) at various flight speeds and heights. Our findings indicate that increasing both flight height and flight speed resulted in larger droplet sizes. This phenomenon is beneficial because larger droplets are less susceptible to environmental wind drift due to their greater mass, thereby increasing their likelihood of depositing within the target area. Conversely, smaller droplets are more prone to drifting away from the intended zone.

Fig. 1 visually depicts the impact of flight height and flight speed on VMD. The VMD was observed to increase with an elevation in flight height from 2 to 4 m and an increase in flight speed from 1 to 5 m/s. The VMD reached its peak value (341.767µm) at a flight height of 4 m and a flight speed of 5 m/s. The optimal VMD range for effective spraying was determined to be between 153.543µm and 341.767µm, with both flight speed and height directly influencing this range. This aligns with previous research by Parmar (2019), who suggested an optimal droplet size between 50 and 400µm for superior spray application.

B. Number Median Diameter (NMD)

Table 1 presents the Number Median Diameter (NMD) across varying flight speeds and heights. Our observations indicate that an increase in both flight height and flight speed led to an increase in droplet size (NMD). This outcome is favorable because larger droplets, due to their greater mass, are less influenced by environmental wind and are thus more likely to deposit within the intended target area. Conversely, smaller droplets face a higher risk of drifting outside the target zone.

Fig. 1 graphically illustrates the effect of flight height and flight speed on NMD. The number median diameter (NMD) was found to increase as flight speed increased from 1 m/s to 5 m/s. The highest NMD value, reaching 92µm, was observed at a flight height of 2 m and a flight speed of 5 m/s. The minimum NMD, however, was noted at a flight height of 2 m and a flight speed of 1 m/s. The optimal NMD typically ranges from 32.58µm to 92µm.

Uniformity coefficient. It is ratio of VMD to NMD, which gives the uniformity of spray. More uniform size of the droplet, the ratio is varies between 3.1 to 4.7 (Ingle *et al.*, 2024).

Table 1 illustrates the Uniformity Coefficient (UC) at various flight speeds and heights. We observed that as both flight height and flight speed increased, the uniformity coefficient (UC) also tended to increase.

The maximum uniformity coefficient was attained at a flight height of 2 m and a flight speed of 1 m/s. Conversely, the minimum uniformity coefficient was observed at a 4 m flight height and a 1 m/s flight speed.

Fig. 1 graphically presents the effect of flight height and flight speed on UC. As flight speed and flight height increased, the UC values generally increased. At lower flight speeds and heights, the UC values were lower, indicating a less uniform spray pattern under these conditions. This highlights that the UC values ranged between 3.111 and 4.713, with the interplay of flight speed and height directly influencing these values.

Droplet density. It is the number of droplets per unit area of the leaf surface usually expressed in number of drop per sq.cm. The droplet density was determined by placing collected glossy paper on microscope (Ingle *et al.*, 2024; Parmar, 2019).

Table 1 illustrates the droplet density observed at various flight speeds and heights. It was found that with increased flight height and flight speed, the droplet density decreased. This is because the spray spreads over a larger area more quickly, thereby reducing the amount of spray per unit area. Furthermore, smaller droplets, which are more prone to drift, mean that only a fraction of the larger droplets effectively reach the plant canopy.

Our observations indicate that the droplet density ranged from 190.670 to 340.630 droplets/cm^2. The maximum droplet density, recorded at 340.630 droplets/cm^2, was observed at a flight height of 2 m and a flight speed of 1 m/s. Conversely, the minimum droplet density occurred at a 4 m flight height and a 5 m/s flight speed.

Fig. 1 graphically demonstrates the influence of flight height and flight speed on droplet density. As the flight height increased from 2 m to 4 m and the flight speed increased from 1 m/s to 5 m/s, the droplet density consistently decreased. This reduction is attributed to the spray spreading more quickly over a larger area, leading to less spray per unit area and an increased potential for drift. The graph clearly suggests that to achieve a higher droplet density (essential for effective coverage in spraying applications), the system should ideally operate at lower flight heights and lower flight speeds.

Table 1: Effect flight height and flight speed on droplet distribution.

Treatment	Flight speed (m/s)	Flight height (m)	VMD (µm)	NMD (µm)	Droplet Density (No. droplets/cm^2)	Uniformity Coefficient
T1	1	2	153.543	32.581	340.630	4.713
T2	1	3	169.107	42.177	293.267	4.009
T3	1	4	186.140	59.830	251.267	3.111
T4	3	2	239.290	65.370	271.373	3.661
T5	3	3	255.933	69.453	231.300	3.685
T6	3	4	271.200	71.603	215.470	3.788
T7	5	2	305.290	92.000	222.950	3.318
T8	5	3	327.570	85.000	205.910	3.854
T9	5	4	341.767	88.000	190.670	3.884

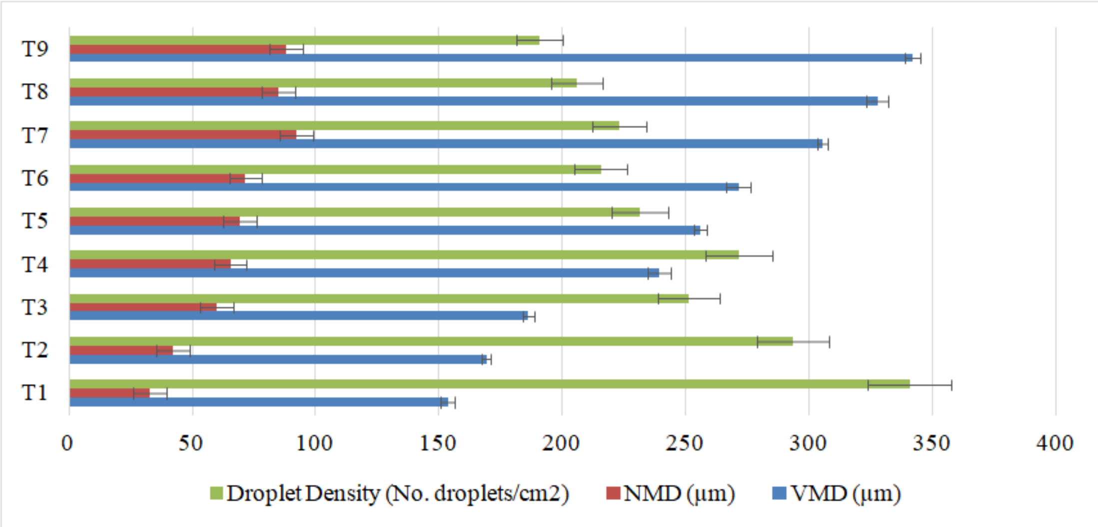

Fig. 1. Graphical representation of effect of flight speed and height on VMD, NMD and Droplet Density.

CONCLUSIONS

This study clearly demonstrates that UAV flight parameters significantly influence spray droplet characteristics, including VMD, NMD, Uniformity Coefficient (UC), and droplet density. Increasing both flight height and speed generally leads to larger VMD and NMD, which is beneficial for reducing drift and enhancing deposition. However, this comes at the cost of reduced droplet density, as the spray spreads over a larger area. Conversely, lower flight heights and speeds yield higher droplet densities, crucial for effective coverage. The UC, indicating spray uniformity, also tends to increase with higher flight parameters. Optimizing UAV spraying requires a careful balance between these interdependent factors to achieve efficient deposition, uniform coverage, and minimal drift.

FUTURE SCOPE

Building upon these findings, future research should focus on: 1. Developing sophisticated models that simultaneously optimize VMD, NMD, droplet density, and UC based on specific crop types, pest targets, and environmental conditions. This could involve machine learning algorithms to predict optimal settings. 2. Integrating real-time sensor data (e.g., wind speed, crop density) with UAV control systems to dynamically adjust flight parameters and nozzle settings for optimized deposition and reduced drift during application. 3. Investigating the impact of advanced nozzle designs (e.g., electrostatic, pulse-width modulation nozzles) on droplet characteristics and their interaction with varying flight parameters to further enhance spray efficiency and uniformity.

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