Pak. J. Agri. Sci., Vol. 56(4), 897-903; 2019
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI:10.21162/PAKJAS/19.8594
http://www.pakjas.com.pk

SPRAY UNIFORMITY TESTING OF UNMANNED AERIAL SPRAYING SYSTEM FOR PRECISE AGRO-CHEMICAL APPLICATIONS

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Excessive agro-chemicals are being used to enhance agricultural production to meet the food security challenge with increasing population. Gaps or overlaps in the spraying patterns can result in under or over application of pesticides thus causing environmental hazards. Conventional sprayers have uniform spray drift that is less effective for heavy canopies. Alternatively, unmanned aerial system (UAS) are being used for crop monitoring and management (spraying insecticides/pesticides) however proper spray height and nozzle opening needs investigation. In this study, a hexa copter unmanned aerial agro-chemical spraying (UAAS) system was tested at different heights and nozzle openings to determine spray uniformity in the field conditions. Operating height of 1.5 m, 2.0 m, 2.5 m and 3.0 m with spray nozzle opening (discharge rate) percentages of 25, 50, 75 and 100% were investigated for variable wind speeds ranging between 1 m/s to 5.8 m/s. Colored spray was used to get impression of spraying droplets on sensitive papers placed for the purpose. Spray dots were counted to get the spraying uniformity at different heights and wind conditions. The hexa copter UAAS system provided a good uniformity and coverage area at operating height of 1.5 m with 50, 75 and 100% spray nozzle opening under wind conditions varying from 1 m/sec to 5.8 m/sec. This investigation provides a guideline to the farmers and service providers entering into the business of spraying through UAS.

Keywords: Aerial spraying, spray uniformity, hexa copter, nozzle opening, agro-chemical.

INTRODUCTION

Agro-chemicals are being widely used in the world for enhancing agriculture production and productivity (Muhammad *et al.*, 2006). However, the World Health Organization report around one million illness cased due to manual spraying of pesticides in the fields (Mogili and Deepak, 2018). It is estimated that annually worldwide about 3 million metric tons of pesticides are used to control the disease (Pimentel, 2009). These chemicals not only control weeds but also help to control insect pest attack that cause the reduction of crop yield and affect the crop quality as well (Li *et al.*, 2009). For example, In Pakistan, the insect pests reported attacking rice crop and causing 20-25% losses to this important foreign exchange earning crop on recurrent basis (Jabbar *et al.*, 1993). On an average, 37% reduction in rice yield has been estimated due to the insect pests (Savary *et al.*, 2000).

In developing countries, including Pakistan, agro-chemicals are being applied on crops to control pests and weeds by conventional spraying systems without considering substantial variation in plant population and canopies (Faical *et al.*, 2017). Now a day's real time monitoring of crop health is possible by using high spectral resolution which help us in real time spraying through chlorophyll content based on vegetation indices (Tahir *et al.*, 2018). Excessive application for the regions without vegetation could result in over-use of the expensive agro-chemicals as well as environmental hazard. The drift and the leaching of the applied agro-chemicals is a threat to the environment as well as underground water reserves. The conventional sprayers used by farmers also have health impacts as the operator is in proximity of the chemical. Such conventional land- spraying machines have become inconvenient for spraying in crops like rice, cotton and sugarcane as well as orchards due to crop growth stages and poor efficiency (Baggio, 2005; Daberkow and McBride, 2003; McBratney *et al.*, 2005; Saizhang and Zhong, 2002). About 40% of all the crops could be affected due to non-uniform spray or late spraying (Peshin *et al.*, 2009). Moreover, the continuous increasing cost of the agro-chemicals and an un-precedent dependence on these chemicals for the increased production leads to an economic threat while below-par application would restrict the crop yield. This leads to the conclusion to apply the plant protection products (PPP) with utmost efficiency in a calculated manner as per the field conditions to avoid environmental pollution and save the cost. Such precise application measures can result up to 5% savings in inputs (Cheema *et al.*, 2018).

With the technology advent, unmanned aerial systems (UAS) are being used in the developed countries for crop monitoring (Latif *et al.*, 2018) and management (spraying insecticides/pesticides) (e.g. Herwitz *et al.*, 2004; Lelong *et al.*, 2008). These UASs have shown large application potential in Asian countries where most of the fields are small scale or fragmented. UAS are also being used for spraying fertilizer especially urea in the crop fields (Iiakiya *et al.*, 2018). While, many researchers (e.g. Xue *et al.*, 2016; Bae and Koo, 2013; Huang *et al.*, 2009) suggested it as a safe and high precision alternative for pesticide spraying as well. Self-adjustment routing mechanism of UAS can help to reduce the wastage of pesticides and application of fertilizers significantly (Faical *et al.*, 2014). Spray rates for such systems are generally 1–2 L/ha, which is 25–50 times lower than conventional spray application systems resulting in reduced input cost. A study conducted by Qin *et al.* (2018), revealed that aerial spraying system could increase efficiency by more than 60% with 20 – 30% decrease in pesticide dose. Such systems are also getting popularity among Pakistani farmers. However, a series of practical issues are making their use difficult. The UAS spraying for insect pest protection needs improvement in vegetation detection, poor penetrability into the crop canopy, droplet coverage ratio, and heterogeneous droplet distribution (Qin *et al*., 2014).

Qin *et al.* (2014) and Yuanyuan *et al.* (2013) conducted research on optimizing UAS for application of pesticides at different crops. Nadasi and Szabo (2011) suggested sprayer altitude of 2.5 m with droplet deposition of 15.6 drops/cm^2 to effectively prevent 80.7% of corn crop from corn borer. While Qin *et al*. (2014) found 7 m optimal operating height and 7 m horizontal spray coverage for corn. Considering the variable results, Gao (2013) suggested that the spray system for UAS should be carefully tested to ensure application accuracy. It was also suggested to fly at low altitude of 1–5 m that will help in avoiding spray drift. Huang *et al.* (2009) carried out spraying tests and concluded that system has the potential to provide accurate and site-specific crop management when uniformity test performed before UAS use for application of agro-chemicals. It was also noted by Qin *et al.* (2016) that the uniformity and quality of spray depend upon expertise and experience of the operator as well. However, Shilin *et al.* (2017) suggested further investigation regarding spraying height, flow rate and penetrability after assessing four different variants of UAS sprayers being used for pesticide application in China.

From 2016-17, unmanned aerial agro-chemical spraying (UAAS) systems are getting popularity in Pakistani farm settings. Many service providers and farmers are willing to adopt the new technology. However, there is no study (based on authors knowledge) available on different flight configurations for altitude and spray nozzle openings that might be helpful for the operators to optimize the UAAS system for Pakistani farming system. Such investigation will reduce the risks of over usage of pesticides due to its outside drift as well as overlapping of area under spray (Faical *et al.*, 2017).

In the current study, an effort has been made to evaluate spraying through UAAS system at different heights and nozzle openings under variable wind conditions. The findings will be first of its kind in Pakistan and will be helpful in recommending efficient spraying through UAS as well as open ways to get benefit from the advanced technology of spraying.

MATERIALS AND METHODS

***Hexa copter unmanned aerial agro-chemical spraying system specifications*:** Hexa Copter UAAS System of Joyance model having six wings and two spray nozzles for downward spray was used in this study. Complete specifications of the system are provided in the Table 01. Six motors were attached on hinges with motor mounts. Spraying tank capacity was 15 liters while drone total takeoff payload capacity was 38 kg. However, 30-32 kg payload was used for safely flying up to 15 minutes; that was enough to spray two acres. Hexa copter UAAS system had smooth take-off and landing in its autonomous mode with flying speed of 1-6 m/s and height of 8 m above ground level. Instructions of flight height, spray span for overlapping of spray or precise spray, speed of flight and turn time was controlled through UAAS software interface.

Table 1. Specifications of Unmanned Aerial Agro-chemical Spraying System.

UAV Part Name	Specifications
No of wings	6
Motors	6
Take-off weight	38 Kg
Flying speed	0-6 m/s
Flying height	0-30 meters
Spray tank capacity	15 liters
Number of spraying nozzles	2
Type of nozzles	Flat fan nozzle
UAV Size (W*L*H)	1.65*1.45*0.47m
Spray span	Up to 4 m
Spray efficiency per hour	≥4 hectares
Flight time	14-15mints

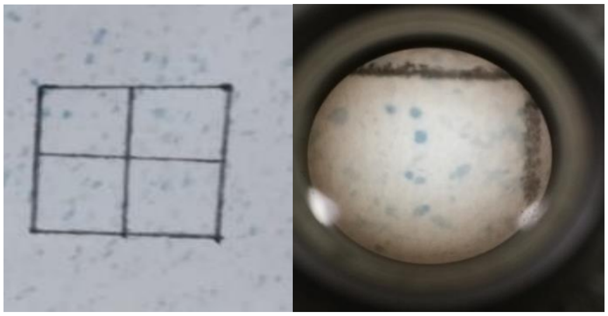
***Uniformity test and data collection*:** Spray uniformity analysis of Hexa copter UAAS system was conducted at open field located near the site of SATUMA, Islamabad-Pakistan (an industrial partner involved in developing indigenized UAAS solution). Research testing site was located at 33.5441 N and 73.1969 E. UAAS system sprayer was tested at four different heights and at variable wind conditions on different days. Spraying samples were taken at 1.5, 2.0, 2.5 and 3.0 m heights at wind speeds of 1.0, 1.8, 2.6, 3.8, 4.6 and 5.8 m/sec. Discharge rate of flat fan spray nozzles (Fig. 1a) were tested for 25, 50, 75 and 100% openings. Water sensitive papers were placed at equal spacing of 5 m up to length of 30 m track to get drone spray impressions (dots/marks). Water sensitive papers were paced after every 5 m distance. Size of paper was 21 cm x 210 cm that covered complete spraying span as shown in Figure 1b.

(a) (b)

Figure 1. **(a) Flat fan nozzle used for spraying and, (b) test flight on sensitive paper at different heights.**

The UAAS system was flown on the fixed path at four heights and nozzle openings on six different days from 26th June to 7th July 2018 to check the spraying under variable wind conditions keeping drone speed constant. The spray droplet impressions on water sensitive paper were observed/counted using light microscope (Figure 2a and 2b) as suggested by Yanliang *et al*. (2017). The number of spray dots per cm^2 were counted. If number, of fine spray dots were equal to or greater than 100 counts, then the spray was considered as uniform (Yanliang *et al*., 2017). If number of spray dots per cm^2 are equal to or greater than 100 counts then we use command "YES" means that level of height, wind speed and spray nozzle opening is recommended for uniform spraying. On the other hand, if the number of spray counts are less than 100 then we use the word "NO" means that height level, wind speed and spray opening nozzle is not recommended for uniform spraying, if do so then it will leads non uniform spray and waste of resources.

After all test trails, statistical analysis of variance (ANOVA) at α=5% is applied on the data to check it level of significance in between groups (rows) and in each group (columns).



(a) (b)

Figure 2. **(a) Spray dot impressions on water sensitive paper, (b) shows microscopic view of dots in a square box.**

RESULTS AND DISCUSSION

Spray uniformity was tested at different altitudes and nozzle openings under variable wind conditions. The spray dots imprinted on water sensitive papers were counted to determine the number of dots per cm^2 that provided information on uniformity of spraying system. Uniformity test results for 50% nozzle opening at 1.8 m/sec wind speed are provided in Table 2. Uniformity at 1.5 and 2 m altitude is observed with 50% nozzle opening while at 3 m flight height; only 46 dots are imprinted thus restricting spraying above 2.5m.

The spray uniformity test results at working altitude of 1.5 m, 2.0 m, 2.5 m and 3.0 m, variable wind speeds and nozzle openings are shown in Figure 3-6. It is evident from the figures that the spray can be effectively done with 50 to 75% nozzle openings at wind speeds less than 6 m/sec with flying height of 1.5 m. however, in case of working height of 2.0 m, efficient working nozzle opening is 75% with the wind speed less than 5 m/sec. it is due to the fact, that at the wind speed of 4.6 m/sec and 75 to 100% nozzle opening give good results while 50% nozzle opening effected by wind speed and give non uniform spray results. However, if wind speed is more than 5 m/sec, then working height should be less than 2.0m to avoid spray losses. At the working height of 2.5 m, 50, 75 and 100% nozzle opening of spraying system provide good uniform results at when wind speed is not more than 2 m/sec. At wind speed 2–3 m/sec only 75 and 100% nozzle opening pass uniformity spray test while at wind speed of 3.8 m/sec only 100% nozzle spraying opening give uniform results that holds true up to 4.5 m/sec wind speed as evident from Figure 5.

Spray uniformity test at 3 m height provide non-uniform patterns in most of the nozzle and wind speed settings. The fine spray particles are greatly affected by the wind speed and unable to reach at the water sensitive paper. Height and high wind speed are the limiting factors affecting that can affect the overall spraying efficiency. The findings are consistent with the observations of Yanliang *et al.* (2017) and Su *et al*.

Table 2. UAAS system spray uniformity at 50% spray nozzle opening and 1.8 m/sec wind speed.

Surface Altitude (m)	Discharge (%)	Box1	Box2	Box3	Box4	Total particles (Number)	Average (Number)	Yes or No
1.5 m	50	40	34	38	39	151	149	YES
		51	41	30	33	155		
		43	24	27	46	140		
2.0 m	50	29	43	27	34	133	126	YES
		35	34	35	37	141		
		23	28	27	26	104		
2.5 m	50	21	34	29	21	105	108	YES
		23	28	29	30	110		
		27	31	32	19	109		
3.0 m	50	10	8	18	10	46	46	No
		10	9	13	13	45		
		12	15	12	7	46		

(2018) who also reported similar results with the UAV based sprayers used in crop protection.

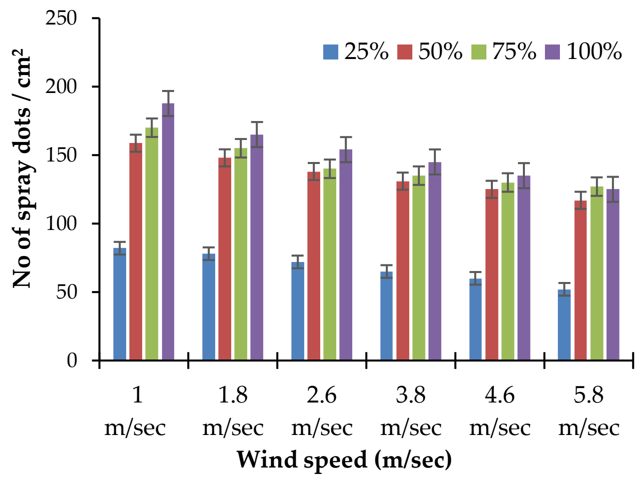


Figure 3. Spray uniformity for different nozzle openings and wind speeds at 1.5 m working height.

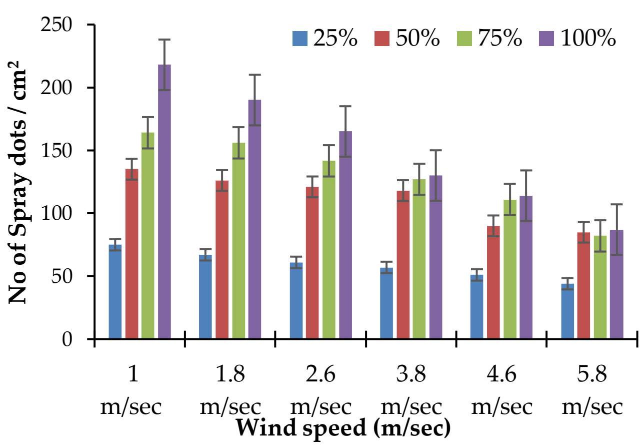


Figure 4. Spray uniformity for different nozzle openings and wind speeds at 2.0 m working height.

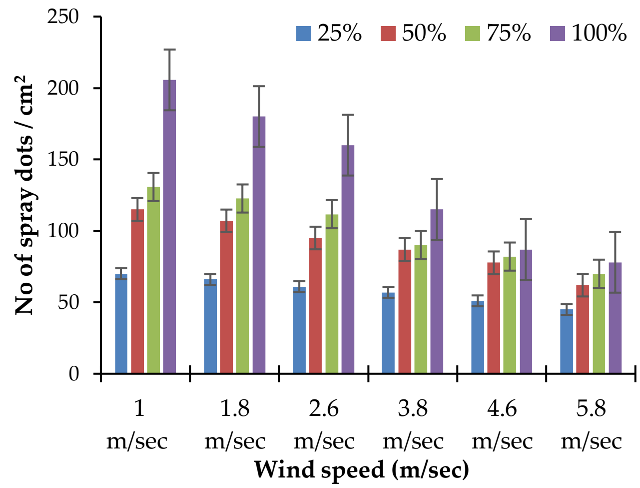


Figure 5. Spray uniformity for different nozzle openings and wind speeds at 2.5 m working height.

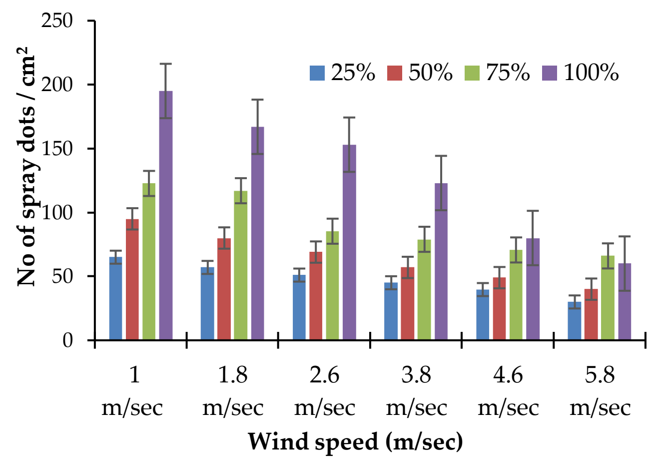


Figure 6. Spray uniformity for different nozzle openings and wind speeds at 3.0 m working height.

From the above Figures, it is evident that the spray usage through UAS can be optimized with the nozzle opening of 50 and 75% instead of 100%. To further simplify the test results for 50 and 75% nozzle openings are provided in the Table 3 and 4, respectively. There 54% YES hits for 50% nozzle opening at tested heights and wind speeds while in case of 75% nozzle opening, 67% YES are observed. Thus, it can be concluded that the with 75% nozzle opening UAAS can spray efficiently at height of 2.0 m or less and wind speed of 5.0 m/sec or less with lesser outside drift or overlapping of pesticides.

Table 3. Uniformity test at 50% nozzle opening under variable wind speeds and working height.

No of dots/cm²		Wind speed (m/sec)						
		1.0	1.8	2.6	3.8	4.6	5.8	
Height (m)	1.5	158	148	138	131	125	117	YES if≥100
	2.0	135	126	121	118	111	85	
	2.5	115	107	95	87	77	62	NO if<100
	3.0	95	80	69	57	49	40	

YES, means configuration passed uniformity test while NO means non-uniform spray configuration.

Table 4. Uniformity test at 75% nozzle opening under variable wind speeds and working height.

No of dots/cm²		Wind speed (m/sec)						
		1.0	1.8	2.6	3.8	4.6	5.8	
Height (m)	1.5	170	155	140	135	130	127	YES if≥100
	2.0	164	156	142	115	107	92	
	2.5	131	123	112	90	82	70	NO if<100
	3.0	123	117	85	79	71	66	

Analysis of variance at α=5% shown in table 5 in which table 3 data is used to check their level of significance. As in table 4 showed that wind, speed have significant effect on spray uniformity at 50% nozzle opening. As we increase the UAAS height with increase of wind speed, it may affect the spray uniformity. It is concluded that, spraying with UAV at 3 m height is not recommended due to non-uniform spray pattern. UAAS height at 1.5 and 2 m with 50% nozzle opening is recommended for uniform spraying.

The results are in consistent with the studies of Yallappa *et al*. (2017), Yongjun *et al*. (2017) and Lou *et al*. (2011). They tested UAS system performance for paddy, groundnut and corn, respectively. They found satisfactory spray results with 2.0m flight height and concluded that flying speed and prevailing wind conditions have effects on the efficiency of the spraying system.

***Conclusions*:** The UAAS systems can be used for precise application of pesticides with less risk of over and under application in different weather conditions. Experimental results reviled that, at 1.5 m UAAS height with 50, 75 and 100% nozzle opening within 1.0 to 5.8 m/sec give uniform spraying results. At 2 m height of UAAS system, good uniformity is attained within 1.0 to 3.8 m/sec wind speed with 50, 75 and 100% spraying nozzle opening. However, in case of high winds it is not recommended to spray through UAAS system as it is verified in table 5 and table 6 at α=5% gives significant results within groups and in each group. The use of UAS in spraying agro-chemicals is relatively new in Pakistan’s farm settings. More research is needed on wide adoptability of this technology especially on improving its working time and coverage. Variable rate spraying through UAS is also a potential area of study.

Table 5. Analysis of variance at 50% nozzle opening.

Source of Variation	SS	df	MS	F	P-value	F crit	Result
Rows	17218.17	3	5739.39	295.21**	1.48E-13	3.29	Significant at 5%
Columns	6320.62	5	1264.12	65.02**	1.25E-09	2.90	
Error	291.63	15	19.44				
Total	23830.42	23					

(*) shows that P value is less than 0.05 and (**) shows that P value is less the 0.01. Analysis of variance at α=5% level of significant shows that different wind speed (m/s) levels and different UAAS heights (m) have significant effect on the spray uniformity at 50% nozzle opening in the field.

Table 6. Analysis of Variance at 75% nozzle opening.

Source of Variation	SS	df	MS	F	P-value	F crit	Results
Rows	10462.49	3	3487.50	52.15**	3.62E-08	3.29	Significant at 5%
Columns	11154.89	5	2230.98	33.36**	1.30E-07	2.90	
Error	1003.20	15	66.88				
Total	22620.58	23					

(*) shows that P value is less than 0.05 and (**) shows that P value is less the 0.01. Analysis of variance at α=5% level of significant shows that different wind speed (m/s) levels and different UAAS heights (m) have significant effect on the spray uniformity at 75% nozzle opening in field level.

***Acknowledgments*:** Authors are highly thankful to Pakistan Higher Education Commission for providing funds for this project under Technology Development Fund (HEC TDF 047). Thanks to the SATUMA industries (Pvt) Limited Islamabad-Pakistan for providing development facility. HEC funded Center for Advanced Studies in Agriculture and Food Security (CAS-AFS), University of Agriculture, Faisalabad is also acknowledged for providing highly efficient working environment.

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