

Efficacy of hexacopter UAV (ANGRAU-PUHSPAK) spraying in managing tobacco caterpillar, *Spodoptera litura*(Fab.) in groundnut

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ABSTRACT

The present study was conducted on Groundnut crop to manage *Spodoptera litura* by chemical application with UAV sprayer in Operational Research Project (ORP), Bapatla District, Andhra Pradesh during rabi 2021-22 and 2022-23. The treatments imposed are in RRBD experimental design with five treatments and four replications with 100%(T1) , 75% (T2) and 50% RDP(T3) with UAV sprayer and 100% RDP with human backpack sprayer (T4) and a control plot with only water spraying with UAV sprayers. The bioefficacy study showed that spraying with UAV sprayer (T5) is more efficient and precise in application and resulted in better control in *Spodoptera litura* larvae, foliar damage and with zero phytotoxicity. Spraying was done at 40 days after sowing (DAS) with Novaluron 5.25% + emamectin benzoate 0.9% EC, Flubendiamide 20% WG and Emamectin Benzoate 5% WG at seven days interval. Treatments with 100% RDP of UAV spraying (T1) shown highest overall mean reduction of foliar damage with 66.41% foliar recovery, 59.82%, 50.35% and 61.59% and 50.7%, 49.2%, 40.0%, 46.28% in T1,T2,T3,T4 respectively during rabi 2021-22,2022-23 and T1,T2,T4 were at par in their efficacy in both seasons. A flight height of 1.0 m height sprayed above canopy, 4.5 m/s during flowering to harvest stage. The recommended dosage with UAV sprayer, Novaluron 5.25% +Emamectin benzoate 0.9% EC with 120 ml acre⁻¹, Flubendiamide 20% WG with 90 gm acre⁻¹, Emamectin Benzoate 5% WG 75 gm acre⁻¹ was found effective without compromising bioefficacy.

Key Words : Emamectin Benzoate 5% WG, Flubendiamide 20% WG, Groundnut, Novaluron 5.25% + Emamectin benzoate 0.9% EC, *Spodoptera litura*, UAV sprayer.

Groundnut is a very important food and cash crop of our country. It has many benefits for human health, nutrition, soil fertility and environment. It is also called as the 'King' of oilseeds. Groundnut is also called as wonder nut and poor man's cashew nut, is grown under varied soil and climatic conditions during *kharif* (rainy), *rabi* (winter) and summer seasons in India. It tops the world in area under cultivation and second largest producer with 101 lakh tonnes in 2021-2022 contributing 19% of global production. Major states which contribute 82.87% of the area and 73.23 % of the production are Gujarat, Andhra Pradesh, Rajasthan, Karnataka and Tamil Nadu. In Andhra Pradesh, it is grown in Anantapur, Chittoor, Kurnool, Kadapa, Nellore, Guntur and Prakasam districts. Guntur is highest in productivity with 4282 kg/ha in 2021-22. (www.Indiastat.com). Groundnut is popular summer crop and valuable cash

crop for millions of small- scale farmers and rainfed farmers in Andhra Pradesh, where it is grown in the coastal agro-ecosystem.

Andhra Pradesh occupies largest area under cultivation but the productivity is very low when compared with other states mainly due to abiotic and biotic factors. The estimated losses by insect pests range from 10 to 30% losses **Baskaran RK and Rajavel DS., 2013**. At the seedling and flowering phases, one *S. litura* larva per groundnut plant might result in a considerable production loss. At the seedling stage, it defoliated 54.70 per cent of the leaf area and decreased pod output by 25.80%. During flowering, it consumed 49.10% of the leaf area and lowered production by 19.00%. At pegging, it defoliated 38.80% of the leaf area, resulting in a 5.7 per cent yield reduction **Dhir et al., 1992**.

In India, drones are advocated primarily as

automated spray device that can be tasked with pesticides, fertilizers, powdery materials and even seeds also owing to reduced health hazard associated with manual spraying and also save time, resources and human labour. One of the possible applications is foliar application of fertilizers and nutrients on groundnut crops. Groundnut is an important pulse crop that requires adequate nutrients for growth and production. Drone sprays save time as 1 spray takes around 5-7 minutes/ acre whereas manually typically a person can cover only 3-4 acres in a day. From the point of view of farmer safety and health concerns due to spraying and other activities in the field, drones provide a good solution. Hence the present experiment was conducted with the objective of standardizing pesticides UAV spraying to improve yield in groundnut.

MATERIAL AND METHODS

The present research was conducted at operational research project (ORP), Bapatla District, Andhra Pradesh during *rabi* 2021-22 and 2022-23. In both the years, the data on parameters required for standardizing operational protocols and data on bio-efficacy, phytotoxicity and plant parameters were recorded and used for the analysis.

Design of Plant Protection UAV for Spraying

A hexacopter UAV was designed and standardized specifically for plant protection spraying in agricultural crops by Acharya N G Ranga Agricultural University. The UAV built by ANGRAU with the specifications as discussed in Table 1, was designated as “ANGRAU- Pushpak-01”, a model RPAS (Remotely Piloted Aircraft System). The registration approval pertaining to the “ANGRAU-Pushpak-01” was obtained based on guidelines issued by Directorate General of Civil Aviation (DGCA) for its usage in agricultural operations for research purpose. The specifications pertaining to technical parameters and payload data of ANGRAU – PUSHPAK -01 drone for spraying are detailed below (Table 1 & Fig 1).

Standardization of UAV weight, spraying height above crop canopy, flight speed, spray width, direction of flight travel and standardization of parameters for aerial spraying with drone operational envelope like ambient temperature, optimal ambient temperature, humidity, wind speeds, wind direction, etc. and optimal time for spraying a unit of land duly

considering the endurance of the batteries, spray fluid volume and uniformity of droplet distribution and their deposition (vertical and horizontal distribution) with ANGRAU

Pushpak-01-UAV were done duly following the procedures given by DGCA, New Delhi.

Details of crop, soil, climate characteristics and experimental design

To conduct the studies, Groundnut TAG 24 was selected which is high yielding and can be grown in *kharif* and *rabi*- summer. It is Erect, semi dwarf, early (102 days) duration variety. Treatments T1-100% RDP sprayed from 1.0 m above crop canopy, T2-75% RDP sprayed from 1.0 m above crop canopy, T3-50% RDP sprayed from 1.0 m above crop canopy, T4-100% RDP sprayed with human back power sprayer and T5-Control (Water Spraying with drone). During the experimental period, all the recommended agronomical practices were followed for raising the crop and the scheduled plant protection treatments were imposed to control *Spodoptera litura* as per the recommendations.

Bio efficacy studies on *Spodoptera litura* :

The bio-efficacy studies were conducted with drone (Figure 1) and human backpack sprayer with three CIB &RC recommended insecticides with recommended dosages (Table2). The sprayings were carried out at 40 DAS, 47 DAS and 54 DAS with seven days interval, when the peak population of *Spodoptera litura* appearance was observed. (i) 10 randomly selected plants from each replication of the respective treatments were tagged for consistent and consequent data collection and (ii) the *Spodoptera litura* population was recorded from one square metre at one day before spraying and at seven days after each spray. The per cent reduction of population over control (% ROC) was calculated by modified Abbott’s formula followed by Flemming and Retnakaran (1985).

Statistical Analysis: The data were transformed to “x+ 0.5 transformation before analysis and subjected

Percentage reduction of *Spodoptera litura* population over control (% ROC)

$$\% \text{ ROC} = 1 - \frac{\text{Post Treatment population in the treatment}}{\text{Pre - treatment population in the treatment}} \times \frac{\text{pre treatment population in the untreated check}}{\text{post treatment population in the untreated check}} \times 100$$

Table 1. Technical parameters of Model Remotely Piloted Aircraft System (MRPAS) “ANGRAU-Pushpak-01” for Plant Protection research

SI. No.	Classification	Parameters
1.	Official Designation	: Model Remotely Piloted Aircraft System (RPAS) approved by DGCA.
2.	Size (mm)	: 1495 mm 1308 mm 500 mm (Arms unfolded with motor and without propellers)
3.	Category of drone	: ‘Small’ category with all up weight of 24.8kg
4.	Motors Type and Specification	: BLDC (Brushless Direct Current) with 180 KV rating; Input Current: 80A; IPX7
5.	Maximum Thrust of each Motor	: 12kg/Axis (48V, Sea Level)
6.	Battery Specification	: 16,000 MAH capacity with charging C rating 5C and discharging C rating :15 C and Burst Discharge rating: 30C; 6S1P; 22.2 V and 355.2 Wh
7.	Spray width	: 2.8 m
8.	Pay Load capacity	: 10-12 kg or Litres
9.	Field Capacity	: 2.5 ha/hr
10.	Spray system	: Hydraulic
11.	Flight mode	: Autonomous
12.	Navigation System	: GNSS
13.	Forward speed of the UAV	: 5.5 m/s
14.	Nozzle type	: Flat fan (VP 110015)
15.	Number of nozzles	: 4 Numbers
16.	Nozzle flow rate	: 0.42 to 0.45 lpm
17.	Spraying direction	: Vertically down
18.	Spray angle	: 110 degrees
19.	Spray fluid volume	: 25 L ha ⁻¹ (Low volume and high concentration)
20.	Radio communication frequency	: 2.40 GHz - 2.4833 GHz
21.	Energy Source	: 2 No.s (1 Set) of 16000 mAh Li-Po battery with 15 C rating



Figure 1. An UAV spraying of recommended chemicals for bio-efficacy and phytotoxicity studies

to one way ANOVA using OP STAT software package. The treatments effect was compared by following Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

Treatment Details

The list of CIB & RC recommended insecticides and their dosages for control of *Spodoptera litura* which were sprayed using UAV sprayer and human back pack sprayer is presented in Table 2.

Overall health of the crop due to drone spraying

The overall health of the plant under UAV spraying and human back pack spraying technology is ascertained from the NDVI values which were used to monitor the crop growth, health and to identify potential diseased parts in the fields. The NDVI

readings were measured using Green Seeker™ handheld sensor which is easy to use optical sensor that instantly measures plant health and vigour. The sensor was held 24-48" (60-120 cm) above the crop canopy and observed the reading on the display. The higher the NDVI value the greater plants density and health.

RESULTS AND DISCUSSION

Standardisation of UAV flight parameters with respect to crop-Groundnut.

The standard operating procedures (SOP's) (Table 3) for drone spraying in groundnut crop using ANGRAU – PUSHPAK -01 (Figure 2) developed as the part of this experiment from vegetative stage to flowering stage were used for imposing the spraying treatments. At the time of operating the drone in field

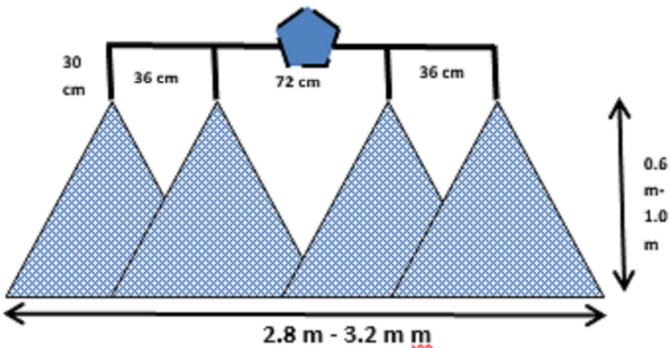
Table 2. Details of the chemicals sprayed using UAV to control *Spodoptera litura*

Treatment No.	Novaluron 5.25% + emamectin benzoate 0.9%	Flubendiamide 20% WG, gm/acre	Emamectin benzoate 5% WG, gm/acre
Dates of Sowing (DAS)	17.01.2021 & 08.01.2023		
Treatment Imposed on	26.02.2021 & 17.02.2023 (40 DAS)	05.03.2021 & 24.02.2023 (47 DAS)	12.03.2021 & 3.03.2023 (54 DAS)
T1	160 ml/acre	120 gm/acre	100 gm/acre
T2	120 ml/acre	90 gm/acre	75 gm/acre
T3	80 ml/acre	60 gm/acre	50 gm/acre
T4	160 ml/acre	120 gm/acre	100 gm/acre
T5	Only Water	Only Water	Only Water



Figure 2. ANGRAU-PUSHPAK 01: An UAV standardized for agricultural spraying

Table 3. SOP's of drone spraying in Groundnut

Sl.No.	UAV Spraying Parameter / Condition	SOP's	Results Observed
A. Standardised parameters for UAV and spraying system			
1.	Weight of the Drone	Small Category – 24.8 to 26.8 kg for spraying	The plants did not lodge, leaves, flowers and fruits did not drop
2.	Spray Fluid Volume	25 L ha ⁻¹ or 10 L acre ⁻¹ (Low Volume Spraying)	This volume is arrived based on relative reduction of the droplet size (100-250 µm) from the conventional technology (300-750 µm) and phytotoxicity studies.
3.	Nozzle Type & Specifications	Flat Fan & VP 110015	Manufacturer specifications
4.	Droplet size of the Nozzle	100-250 µm	Through water sensitive paper studies
5.	Discharge of each nozzle	0.42 to 0.45 lpm	Measured through Discharge test
6.	No. of Nozzles in Hexacopter	4 Nozzles	
7.	Arrangement of Nozzles	Beneath the rotors and strictly avoid boom arrangement to avoid formation of vertices which cause non-uniform spraying.	
8.	Spacing, vertical distance and arrangement of 4 nozzles on the drone. (Under 5 Kmph wind speed and 35 ⁰ C- static condition at 0.6-1.0 m height above crop canopy).	<ul style="list-style-type: none"> • Beneath the rotors at 30 cm from the arms axis. • Distance between nozzles from each other on either side at 36 cm. • The nozzle flow fan should be vertically downwards without any obliqueness. The nozzles should be adjusted accordingly. • All the nozzle tips must be aligned to be in horizontally parallel 	
B. Standard Flight parameters			

		Sl. No.	Item	Drone Flight Height, m above crop canopy	Width of Spraying, m	Forward Speed of UAV, m/s	Arrived by studying the iterative operations to match 10 L delivery with speeds, widths and corresponding heights of spraying with no crop damage and with 10-15% drift losses
9.	Optimal flight height (above crop canopy), Optimal drone forward speed and corresponding width of spray coverage	1.	Vegetative stage to Before Flowering stage	0.6-1.0	2.8	5.5	
		2.	From flowering stage onwards	1.0-1.5	3.2	4.5	
10.	Recommended diurnal Schedule of drone spraying	8-11 A.M. & 3.00 P.M. to 6.00 P.M. (Avoid Rainy periods)				Arrived based on the wind speeds & prevailing temperatures and corresponding spray coverage	
11.	Optimum wind speeds recommended	3-10 kmph wind speeds are good for insecticides, fungicides and foliar nutrients, PGR, PGI's etc. and for herbicides, <5 kmph wind speeds are recommended with reduced flight height.					
12.	Drone flight direction for spraying	The direction of drone travel must be parallel to the longest side of the field. During exigencies, if wind speeds >10 kmph are prevailing, direction of drone travel must be parallel to the direction of the wind.					
13.	Drift	0.5-1.5 m effective drift on either side at 5-10 kmph wind speeds and temperature of about 35-40 °C is found.					
14.	Optimal ambient temperature envelope	35-40 °C. Drone spraying above 40 °C results in excessive vapour drift causes low bio-efficacy.					
15.	Time for Drone spraying	1. Net Time of 15 min. ha ⁻¹ and 2. Gross Time of 24.71 min. ha ⁻¹ (Including chemical filling, nozzle checking, battery replacement and pilot instructions to the farmers).					
16.	Field Capacity of recommended 10L payload spraying drone	2.43 ha hr ⁻¹					

conditions of groundnut crop, which was at flowering stage & pegging stage *i.e.*, at 40 DAS, 47 DAS, 54 DAS, the plant heights were ranging from 16.5 – 26.8 cm.

Biometric Observations (Plant heights and NDVI values)

In 2021-22, plant heights were in range of 16.2 cm to 16.8 cm before spray and at the end of the two sprays, plant heights were in range of 22.0 cm – 26.8 cm against 17.45 cm in control with the highest in T4 (26.8 cm), T2 (25.15 cm), T1 (24.45 cm), T3 (22.00 cm) which were at par indicating no change in plant growths before and after sprays. In 2022-23, plant heights were in range of 17.00 cm to 17.20 cm before spray and at the end of the two sprays plant heights were in range of 22.58 cm - 25.35 cm against 18.15 cm in control with the highest in T2 (25.35 cm), T4 (25.20 cm), T1 (24.35 cm), T3 (22.58 cm) which were at par representing no change in plant growths. NDVI values which are indicators of phytotoxicity were taken before spray and after spray and it was of 0.79 before spray during 2021-22. After two sprays NDVI values were 0.86 (T1), 0.85 (T2), 0.85 (T4) which were at par and 0.73 (T3), 0.63 (T5) values represented no change in chlorophyll content and growth. In 2022-23, after two sprays also no phytotoxicity and no change in

chlorophyll content was observed except in T4 and T5 as represented in Table 4.

Bio-efficacy of Novaluron 5.25% + Emamectin benzoate 0.9 % EC, Flubendiamide 20% WG, Emamectin benzoate 5% WG with UAV and Human back Motorized sprayers against Spodoptera litura with its Foliar damage

The pre-treatment count of number of larvae ranged from 8.0 – 8.75 per metre and 4.17 to 4.67 per metre and 11.8% to 12.95% and 11.35% to 13.81% percent leaf damage during *rabi* 2021-22 and 2022-23 respectively as represented in table 5 & 6. During 2021-22, the first spray with Novaluron 5.25% + emamectin benzoate 0.9 % EC @ 160 ml acre⁻¹ showed highest mortality in T1 (37.32%), T2 (38.20%) which were significant and on par with each other. After second spray with Flubendiamide 20% WG @ 120 gm acre⁻¹, highest mortality was found in T1 (67.36%), T2 (67.36%), T4 (63.90%) which were significant and on par. After third spray with Emamectin benzoate 5% WG @ 100 gm acre⁻¹, highest mortality in T1 (91.58%), T2 (90.70%), and T4 (86.08%) in which were significant and on par. In 2021-22, highest reduction in foliar damage was observed in T1 with 66.41%, T4 (61.59%), T2 (59.82%), T3 (50.35%) respectively (Table 6).

During 2022-23, the first spray with Novaluron 5.25% + emamectin benzoate 0.9 % EC @ 160 ml acre⁻¹

Table 4. Biometric Parameters in Different Treatments in Drone Spraying in Groundnut (*rabi* 2021-22 & *rabi* 2022-23)

TREATMENT	Plant height (cm)				NDVI (indicators of phytotoxicity)			
	<i>Rabi</i> , 2021-22		<i>Rabi</i> , 2022-23		<i>Rabi</i> , 2021-22		<i>Rabi</i> , 2022-23	
	1 DBS	7 DASS	1 DBS	7 DASS	1 DBS	7 DASS	1 DBS	7 DASS
T1	16.5	25.45 ^a	17.12	24.35 ^a	0.79	0.86 ^a	0.8	0.87 ^a
T2	16.2	25.15 ^a	17.2	25.35 ^a	0.79	0.85 ^a	0.82	0.85 ^a
T3	16.5	22.00 ^a	17	22.58 ^a	0.79	0.73 ^b	0.82	0.72 ^b
T4	16.8	26.8 ^a	17.17	25.20 ^a	0.79	0.85 ^a	0.83	0.85 ^a
T5	16.5	17.45 ^b	17	18.15 ^b	0.79	0.63 ^c	0.81	0.63 ^c
C. D. @ 5%	NS	3.25	NS	3.01	NS	0.03	NS	0.03
C. V.%	4.01	7.89	4.25	8.53	0.75	2.5	0.81	2.1

Values followed by same alphabet in the same column do not differ significantly at 5% level of significance; NS: Non-significant at 5% level of probability. (DASS :Days After Third Spraying)

Table 5. Bio-Efficacy of different treatments against tobacco caterpillar in groundnut.(rabi,2021-22&2022-23).

TREATMENTS	<i>rabi</i> , 2021-22 Percent mortality of larva over control				<i>rabi</i> , 2022-23 Percent mortality of larva over control			
	Novaluron 5.25% +Emamectin benzoate 0.9 % EC		Flubendia mide 20% WG	Emamectin Benzoate 5% WG	Novaluron 5.25% +Emamectin benzoate 0.9 % EC		Flubendia mide 20% WG	Emamectin Benzoate 5% WG
	1 DBS	7 DAFS	7 DASS	7 DATS	1 DBS	7 DAFS	7 DASS	7 DATS
T1	8.7	37.32	67.36	91.58	4.3	42.06	53.17	97.94
		(37.38) ^a	(55.19) ^a	(75.77) ^a		(40.3) ^a	(46.84) ^a	(84.12) ^a
T2	8.5	38.2	67.36	90.7	4.17	42.49	50.83	96.38
		(38.00) ^a	(55.14) ^a	(75.56) ^a		(40.64) ^a	(45.47) ^a	(81.05) ^a
T3	8.75	13.27	45.61	73.37	4.67	14.58	36.34	79.7
		(20.76) ^b	(42.45) ^b	(59.1) ^b		(21.28) ^b	(36.63) ^b	(63.27) ^b
T4	8.3	24.59	63.9	86.08	4.52	33.9	51.26	94.96
		(28.96) ^b	(53.08) ^a	(68.21) ^a		(35.51) ^a	(45.74) ^a	(79.20) ^a
T5	8	0	0	0	4.25	0	0	0
C.D. at 5%	NS	8.34	4.09	12.62	NS	6.84	8.41	9.79
C.V. (%)	4.13	17.3	6.4	14.51	2.95	15.95	15.23	10.22

Figures in parentheses are arcsine transformed values . Values followed by same alphabet in the same column do not differ significantly at 5% level of significance; NS: Non-significant at 5% level of probability. (DAFS :Days After First Spraying, DASS : Days After Second Sprayer, DATS :Days After Third Spraying)

Table 6. BioEfficacy of different treatments against leaf damage in groundnut. (rabi, 2021-22 & 2022-23).

TREATMENTS	<i>rabi</i> , 2021-22 Percent leaf					<i>rabi</i> , 2022-23 Percent leaf damage by larva				
	Novaluron 5.25%		Flubendi amide	Emamect in	Reducti on over	Novaluron 5.25%		Flubendi amide	Emamect in	Reducti on over
	1 DBS	7 DAFS	7 DASS	7 DATS	Mean	1 DBS	7 DAFS	7 DASS	7 DATS	Mean
T1	12.9	15	17.75	16.2	66.41%	11.35	14.47	15.32	15.91	50.70%
		(22.72) ^a	(24.80) ^a	(23.74) ^a			(22.31) ^a	(23.20) ^a	(23.49) ^a	
T2	12.5	18.5	18.35	19.9	59.82%	12.7	16.32	17.47	19	49.20%
		(25.50) ^b	(25.35) ^a	(26.46) ^a			(23.79) ^a	(24.69) ^a	(25.85) ^a	
T3	12.8	23.2	23	25.6	50.35%	13.81	18.4	23.22	26.18	40.00%
		(28.8) ^b	(28.64) ^b	(30.37) ^b			(25.50) ^b	(28.8) ^b	(30.75) ^b	
T4	12.95	17.47	19.93	18.8	61.59%	11.89	15.2	18	19.04	46.28%
		(24.69) ^a	(26.01) ^a	(25.67) ^a			(22.86) ^a	(25.15) ^a	(25.81) ^a	
T5	11.8	33	44.23	56.1	0	12.93	21.29	30.42	53.76	0
		(35.07) ^c	(41.66) ^c	(48.51) ^c			(27.45) ^c	(33.35) ^c	(47.16) ^c	
C.D. at 5%	NS	2.08	2.6	2.91	NS	2.14	3.7	4.18		
C.V. (%)	8.91	4.94	5.7	6.15	8.91	5.73	9.733	8.83		

Figures in parentheses are arcsine transformed values and values with same alphabet in the same column do not differ significantly at 5% level of significance)

showed highest mortality in T1 (42.06%), 42.49% (T2), 33.90% (T4) which were significant and on par. After second spray with Flubendiamide 20% WG @ 120 gm acre⁻¹, highest mortality was found in T1 (53.17%), T4 (51.26%), T2 (50.83%) which were significant and on par. After third spray with Emamectin benzoate 5% WG @ 100 gm acre⁻¹, highest mortality was observed in T1 (97.94%), T2 (96.385%), T4 (94.96%) which were significant and on par. In 2021-22, highest reduction in foliar damage was observed in T1 (50.7%), T2 (49.2%), T4 (46.28%) , T3 (40.0%) respectively.

The studies of Kanth *et al.* 2016 described Flubendiamide 39.35% SC as new lepidopteran insecticide, that acts by ingestion and disrupts Ca⁺² balance in nervous system resulting in rapid cessation of feeding and extended residual control and reported the LC50 as 0.005 and 0.002 with relative toxicity values of 8 and 17 by topical and leaf dip methods respectively and LC90 value as 0.09 by topical method, which was 3.2 folds higher than recommended concentration 0.025 per cent (CIB & RC) for the control of this pest. But the LC90 value by leaf dip method was lower than that of the recommended concentration for the control of this pest. This may be due to the effectiveness of flubendiamide by oral ingestion method. Jayewar *et*

al., 2018 also reported 51% reduction over control with flubendiamide 39.35% in field condition.

The studies of Kanth *et al.*, 2016 reported that Emamectin benzoate stood first in LC50 and LC90 values both by the topical and leaf dip methods and the authors also reported that emamectin benzoate was more toxic to *S. litura* larvae by leaf dip method than by topical application method. As Polar nature (lipophilic) of emamectin benzoate is a limiting factor for its penetration through the insect cuticle by topical application method. Hydrophilic nature of the toxicant results in reaching the target site faster due to its better solubility in digestive enzymes and hemolymph. The results of Mastan Shareef *et al.*, 2022 reported indicated that after 72 hrs after application emamectin benzoate proved to be highly toxic to *S. frugiperda* with the least LC50 (1.0 ppm), LC75 (2.7 ppm) and LC90 (6.7 ppm) values followed by spinetoram, chlorantraniliprole, novaluron + emamectin benzoate [LC50 (7.7 ppm), LC75 (15.7 ppm)] and novaluron [LC90 (29.8 ppm)], novaluron + indoxacarb, flubendiamide, in topical application method. Karuppaiah *et al.*, 2017 reported Security index (SI) with SI value of e" 1 indicates that insecticides are likely to be completely effective formulations to all three field populations and the highest security was obtained with emamectin benzoate (SI -28.57),

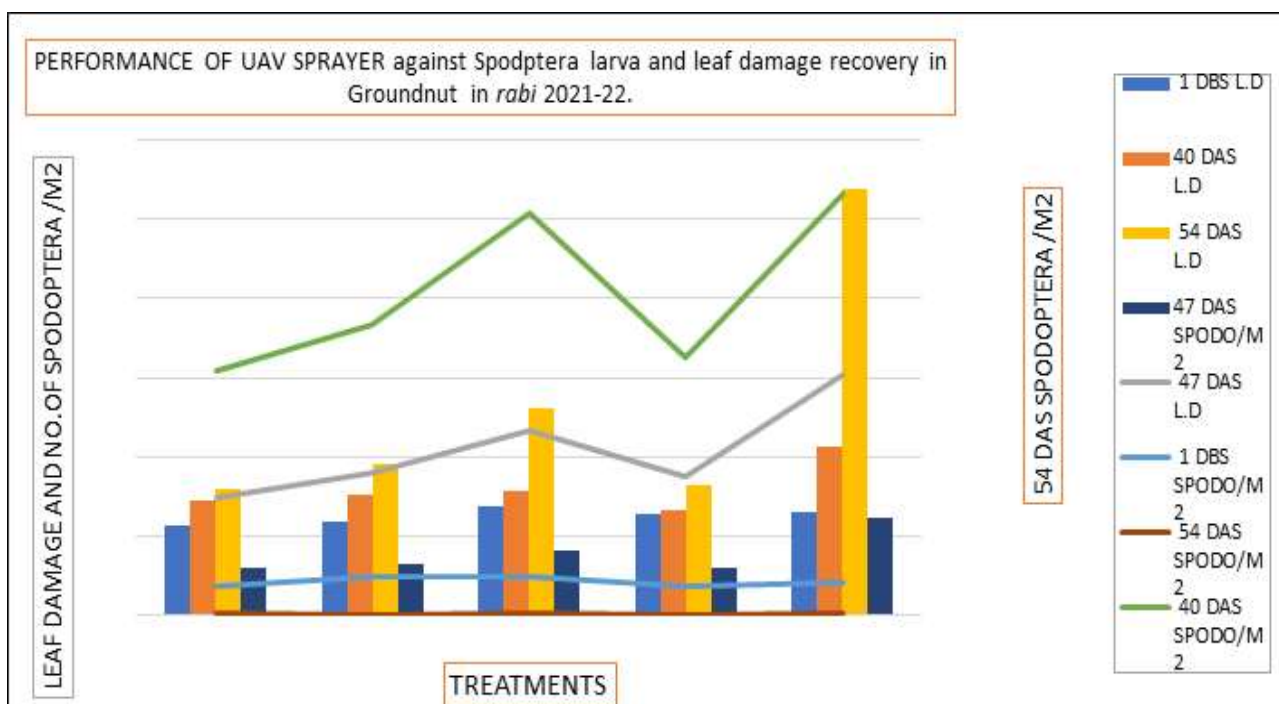


Fig. 3 : Leaf damage percentages and Spodoptera /m² with UAV sprayer vs Human Back Sprayer in rabi 2021 & 2022

Flubendiamide (SI-0.35) showed less toxicity against *S. litura* than emamectin benzoate. Waykule *et al.*, 2020 reported 52.28 % reduction in *spodoptera* larva at 7 days after single spray of emamectin benzoate. The above results are in line with Hu. *et al.*, 2021 who experimented with UAV and manual sprayer and found control efficacy of UAV ranged from 47.63 % - 80.53% which was on par with MAP sprayer and best control efficacy of UAV was found at 1.0 m -1.5 m above crop with 22.5 to 30 L /ha in cotton early stages against aphids and mites with height comparable to groundnut. Yallaapa *et al.*, 2022 reported in the

spray drift test that, there was a higher droplet deposition rate, area coverage, and droplet density in the target area as compared to non-target area in red gram which showed downwash air produced by UAV sprayer improved penetrability of insecticides. The studies of Wang *et al.*, 2019 reported, the deposition of the UAV sprayer on the third top leaf (bottom canopy) was only 0.26 µg/cm², which was not significantly different from the other two conventional sprayers (Knapsack sprayer and knapsack mist blower) on third top leaf indicates the better droplets penetrability in wheat crop and can improve with the

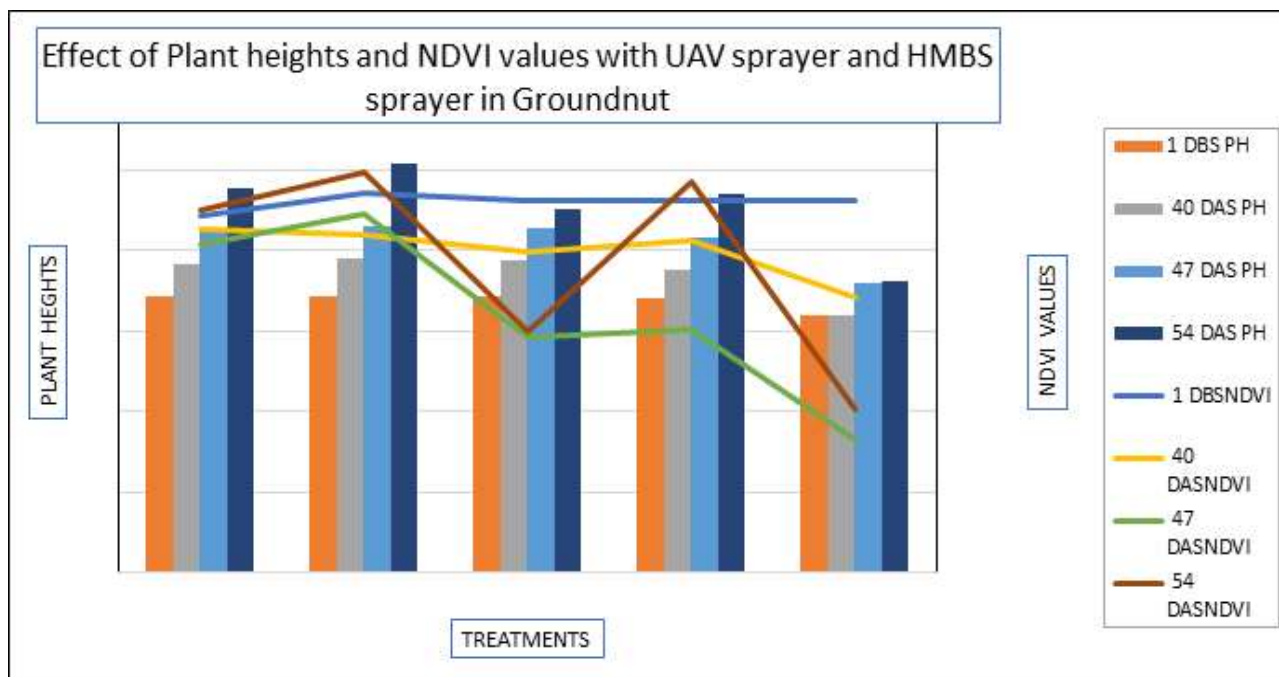


Fig. 4 : Effect of Plant heights and NDVI values with UAV sprayer vs Human Back Sprayer in *rabi* 2021 &2022

Table 7. Phytotoxicity in Cotton with spraying of Flubendiamide 20% WG.

Treatments	Dosage / ha			Equipment for Application	Yellowing (DAA*)			Stunting (DAA)			Necrosis (DAA)			Epinasty (DAA)			Hyponasty (DAA)			Wilting (DAA)			Scorching (DAA)		
	a.i. (g)	Formulation (ml ha ⁻¹)	Water volume L ha ⁻¹		1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5
T1	60	300	25	10 L Pay load Drone	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T2	45	225	25		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T3	30	150	25		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T4	60	300	200	Human Back pack Sprayer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T5	Water		25	10 L Pay load Drone	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*DAA – Days after application

plant with less height crops like groundnut in present studies. Yallappa *et al.*, 2022 also reported the droplet deposition density was the highest in the upper layer (47 ± 4.04 , 53 ± 3.61 , and 52 ± 8.74 droplets cm^{-2}), middle (42 ± 2.52 , 43 ± 8.50 , 38 ± 2.52 droplets cm^{-2}), and lower layers (22 ± 4.36 , 17 ± 3.51 , and 19 ± 4.51 droplets cm^{-2}) in red gram crop when placed at 210 cm, 110 cm, 40 cm above ground level but may have better droplet density in all three layers with less height crop.

Phytotoxicity due to spraying of chemicals with UAV sprayer at low volume:

The results of phytotoxicity study (Table 7) that includes the scaling of yellowing/Chlorosis, stunting, necrosis, epinasty, hyponasty, wilting and scorching at 1, 3 and 5 days after spraying revealed that Flubendiamide 20% WG @ 120 gm acre^{-1} imposed on cotton crop from flowering stage to fruiting stage across all treatments did not show any phytotoxicity.

CONCLUSION

UAV spraying to control *Spodoptera litura* found effective and efficient in managing the pests and in utilizing the pesticide substance delivery and deposition when compared to human backpack spraying. The recommended dosage with UAV sprayer, Novaluron 5.25% +Emamectin benzoate 0.9% EC with 120 ml acre^{-1} , Flubendiamide 20% WG with 90 gm acre^{-1} , Emamectin Benzoate 5% WG 75 gm acre^{-1} was found effective due to aerodynamic forces of the drone and also, induces additional kinetic energy to the vertically downward moving spray fluid droplets, thus causing decreased drift, increased penetration and deposition on the on-target surfaces. The spray fluid volume of 25 L ha^{-1} for UAV spraying is found to be technically feasible instead of 500 L ha^{-1} used for human back pack knapsack sprayers, which offers reduction in use of precious water resource for spraying by 95%, which is highly suitable without affecting the bio-efficacy and without causing phytotoxicity on the crop. The larva was effectively controlled with mortality of 91.58%, 90.70%, 86.08% & 97.94%, 96.38%, 94.96% in 100% ,75% RDP with UAV sprayer and 100% RDP HMBs (Halomethoxybenzenes) in both seasons and found at par. After assessing spraying effect flight height of 1.0m to 1.5 m and spray volume of 25 L/ha are optimal

parameters for UAV spraying in groundnut.

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