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Performance Evaluation and Standardisation of Hexacopter Unmanned Aerial Vehicle (ANGRAU – Pushpak) Spraying in Managing Leafhoppers in Cotton

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ABSTRACT

Application of pesticides and chemicals are essential to control pests and diseases for sustainable yield in cotton. The Unmanned Aerial Vehicles (UAV) have revolutionized Indian agriculture by optimizing the use of inputs precisely for several purposes like spraying, seeding and fertilizer application and has the potential to reduce the input costs and can have rapid control of pests and diseases effectively by overcoming the labour shortage menace in Indian Agriculture. The precision substance delivery mechanism of UAV spraying offers vast opportunity to reduce the pesticide consumption with maximum bio-efficacy for controlling one of the sucking pests complex i.e., leafhoppers in cotton. The study was conducted at operational research project (ORP) site at Lam village of Guntur District, Andhra Pradesh during kharif 2021 & 2022 in restricted randomized block design. The recommended doses of Flonicamid 50% WG issued by Central Insecticide Board and Registration Committee (CIB and RC) Govt. of India were considered for the evaluation. The treatments imposed were of 100%, 75% and 50% Recommended dose of Pesticide (RDP) with UAV and 100% RDP with human backpack sprayer and a control plot with only water spraying with drone for asserting the efficacy of drone spraying when sprayed at low volume spraying (25 L per ha).

During kharif 2021, Flonicamid 50% WG insecticide was sprayed at 62 DAS (Days After Sowing) and pre and post spraying (3 days after spraying) counts were also recorded. Treating the cotton crop with 100% RDP (T1), 75% RDP (T2), 50% RDP (T3) with UAV and 100% RDP with human back pack sprayer (T4) and control (T5) reduced number of leafhopper per 3 leaves from 16.62 to 3.5, 16.75 to 5.02, 17.00 to 9.25, 17.00 to 7.05, 16.8 respectively with a percent reduction over control of 78.57%, 70.09%, 44.34% and 58.04% respectively. During kharif, 2022, imposition of treatments at 66 DAS reduced number of leafhoppers per three leaves from 13.75 to 2.62, 14.75 to 3.65, 13.75 to 10.5, 14.5 to 6.00, 14.75 to 15.25 in respective treatments with a percent reduction over control of 82.79%, 76.07%, 31.15 and 60.66%. The dosage of insecticide Flonicamid 50% WG with 75% RDP using UAV sprayer at the rate of 90 gm acre^{-1} was effective in controlling leafhoppers in cotton.

Key words: *Amrasca biguttula biguttula, Cotton, Flonicamid 50% WG and UAV spraying*

Cotton is one of the most important commercial crops playing its role in economic, political and social affairs from past as a fiber crop. In India, it plays a crucial role in the industrial and agricultural economy. Cotton provides the basic raw material for the textile industry and provides direct livelihood to around 6 million farmers and about 40- 50 million people are employed in cotton trade and processing.

India ranks first in the world in respect of cotton acreage with 120.69 lakh hectares *i.e.*, around 36% of world area of 333 lakh hectares and fourth in total seed cotton production. Andhra Pradesh stands in the seventh place in terms of area and production.

The state has sharply increased the cotton acreage target to 6.11 lakh hectares with a production of 17.85 lakh tonnes with productivity of 504 kg ha^{-1} for 2022 (Cotton Outlook 2022). Cotton yields have been succumbed due to the emergence of sucking pests in *Bt* cotton. Initial control of sucking pest, leafhoppers, play a key role in having good and deciding yields. Leafhoppers cause yellowing, curling and drying of leaves and reduce the yield and quality of cotton lint. They are most active during hot and dry weather spells and cause crop losses up to 22.58% (Prasad and Ashwini, 2021).

In recent years, pests attack in cotton resulted in low yields. Hence, development and usage of advanced plant protection machinery can be boon to cotton farmers (Sambaiah *et al*., 2022). During the seedling stage, cotton plants have low leaf area indices which often require less rates of pesticide. When a large volume sprayer is used, it typically leads to overuse of pesticides and when crop grows, ground based machinery has difficulty in spaying and can even damage the cotton crop (Hu *et al*., 2021). Drone spraying technology is widely used because of its unique advantage of water saving and pesticide application characteristics as well as high operating efficiency with no damage to cotton bolls while operating (Lou *et al.*, 2018).

Drone technology can transform traditional farming methods in an easy way to increase the efficiency and productivity of farmers. Spraying using kisan drones for crop pest control can increase productivity, accuracy rate and reduce time of spraying, cost of application and provide safety assurance. Drone technology will be a boon to dry land cotton farming where water and labour are the major constraints. Cotton forms roughly 5% of the gross cropped area in the country while consuming 36%–50% of the total pesticides in the country (Bhardwaj and Sharma, 2013).

Keeping in view of above constraints *i.e.*, high input cost in terms of pesticides dose and unavailability of labour, the present study was undertaken to study the efficacy of drone aided farming.

MATERIAL AND METHODS

The present research was conducted at Regional Agricultural Research Station, Lam, ANGRAU, Guntur, during the years 2021-22 and 2022-23. The phytotoxicity and bio-efficacy were studied during the UAV spraying of CIB and RC recommended chemicals against cotton leafhopper *Amarsca biguttula biguttula*.

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 (Figure 1 & Table 1).

Figure 1. ANGRAU-PUSHPAK 01: An UAV standardized for agricultural spraying

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 X 1308 mm X 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 1C -3C charge rating, 15C discharge rating & 30C burst discharge rating

Standardization of spraying height, time, direction of spray, drift, ambient temperature, time taken for drone flight, spray fluid volume and regularity of distribution of droplet deposition (vertical distribution) with ANGRAU Pushpak-01-UAV were done following the procedures given by Directorate General of Civil Aviation, New Delhi.

Bio efficacy studies on *Amarasca biguttula biguttula*

The bio-efficacy studies were conducted with Flonicamid 50% WG by taking recommended dosage given by CIB and RC. The insecticide was sprayed with drone and human back pack sprayer against leafhoppers in cotton crop sequentially at 7 days interval from 62 and 66 days after sowing (DAS) in 2021, 2022 respectively when the peak population of leafhoppers was observed on cotton. (Figure 2).

The insecticides were tested for their efficacy against leafhoppers at 100%, 75% and 50% recommended doses of pesticide (RDP) using drone, 100% RDP with human back power spray and water spray with human back power spray as control. The experimental design details are given below in Table 2.

Table 2. Details of crop, location of field traits, season, soil characteristics and field layout

Variety/Hybrid	Cotton, Akira BG -II (Tulasi – 171 BG II) (High yield, Less internodal distance or Chain Bearing Very high number of bolls per plant)
Age of the Crop when spraying was done	62 DAS in 2021 and 66 DAS in 2022.
Spacing	120 x 45 cm
Location	Lam, Guntur district, Andhra Pradesh
Season	*kharif* 2021-22, 2022-23.
Soil type	Clay loams
Area	5 acres
Design	RRBD (Restricted Randomized Block Design)
Treatments	5
T1	100% RDP sprayed from 0.6 -1.0 m above crop canopy
T2	75% RDP sprayed from 0.6 -1.0 m above crop canopy
T3	50% RDP sprayed from 0.6 -1.0 m above crop canopy
T4	100% RDP sprayed with human back pack sprayer
T5	Control (Water Spraying with drone)
Replications	4

All the recommended agronomical practices were followed for raising the crop except plant protection for cotton leafhoppers.

Insecticide spray description

The insecticide used in the present experiments was Flonicamid 50% WG - Ulala supplied by UPL Company. The normal dosage in cotton for 100% RDP, 75% RDP, 50% RDP and 100% RDP with UAV and human back sprayer was 150 gm ,90 gm, 75 gm, 150 gm per hectare, respectively. The spray fluid applied with human back pack motorized sprayer was 200 L acre^{-1}, whereas with UAV, a total of 10 L spray fluid was applied per acre.

Bio-efficacy Studies

Ten plants were selected randomly in each block. The randomly selected plants were from central area of the plot. The number of leafhoppers were counted on each plant before spray and it was further counted on 3rd, 5th and 7th day after spraying. Data were converted into per cent reduction over control (% ROC).

%ROC =

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

Observations for phytotoxicity were taken on 1, 3 and 5 days after the insecticide application for the specific parameters like chlorosis, necrosis, wilting, scorching, hyponasty and epinasty (Table 3). Normalized Difference Vegetation Index (NDVI) values were used to monitor the crop growth, health and to identify potential diseased parts in the fields. 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 the reading was observed on the display. The higher the NDVI value, the greater plants density and health. The standard operating procedures (Table 4) for operating the drone in field conditions of cotton crop considering the minimum to maximum plant heights of cotton ranging from 75 cm at 62 DAS to 115 cm in *kharif* 2021 and 78.75 cm at 66 DAS in *kharif* 2022 were used. An UAV (Figure 1) was used for spraying of the chemicals on cotton crop. The data on the per cent reduction over control, per cent leaf damage and per cent disease index were transformed to arc sine values before analysis and subjected 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).

RESULTS AND DISCUSSION

The results of the experiment conducted to control leafhopper through UAV and human back pack sprayer equipment with recommended chemicals are presented as detailed below.

Standard Operating Procedures (SOP's)

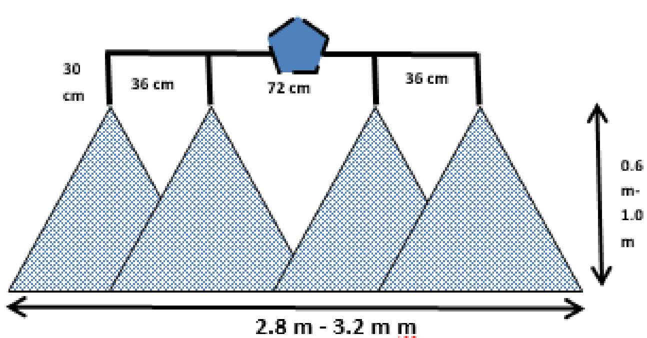
The standard operating procedures (SOP's) (Table 4) for drone spraying in cotton crop using ANGRAU – PUSHPAK -01 developed as the part of this experiment were used for imposing the spraying treatments. At the time of operating the drone in field conditions of cotton crop, which is at flowering stage, *i.e.*, at 62 DAS in *kharif*, 2021 and 66 DAS in *kharif*, 2022.

Figure 2. An UAV spraying of recommended chemicals on cotton

Table 3. Grading scale for phytotoxicity measurement

Score	Phytotoxicity (%)	Score	Phytotoxicity (%)
0	No phytotoxicity	6	51 – 60
1	0 – 10	7	61 – 70
2	11 – 20	8	71 – 80
3	21 – 30	9	81 – 90
4	31 – 40	10	91-100
5	41 – 50		

Table 4. SOP's of drone spraying in Cotton

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).	· 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  	

<table>
<tr><th>B.</th><th colspan="7">Standard Flight parameters</th></tr>
<tr><td rowspan="3">1.</td><td rowspan="3">Optimal flight height (above crop canopy), Optimal drone forward speed and corresponding width of spray coverage</td><td>Sl. No.</td><td>Item</td><td>Drone Flight Height, m above crop canopy</td><td>Width of Spraying, m</td><td>Forward Speed of UAV, m/s</td><td rowspan="3">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</td></tr>
<tr><td>1.</td><td>Vegetative stage to Before Flowering stage</td><td>0.6</td><td>2.8</td><td>5.5</td></tr>
<tr><td>2.</td><td>From flowering stage onwards</td><td>1.0</td><td>3.2</td><td>4.5</td></tr>
<tr><td>2.</td><td>Recommended diurnal Schedule of drone spraying</td><td colspan="4">8-11 A.M. & 3.00 P.M. to 6.00 P.M. (Avoid Rainy periods)</td><td colspan="2">Arrived based on the wind speeds & prevailing temperatures and corresponding spray coverage</td></tr>
<tr><td>3.</td><td>Optimum wind speeds recommended</td><td colspan="6">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.</td></tr>
<tr><td>4.</td><td>Drone flight direction for spraying</td><td colspan="6">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.</td></tr>
<tr><td>5.</td><td>Drift</td><td colspan="6">0.5-1.5 m effective drift on either side at 5-10 kmph wind speeds and temperature of about 35-40 ^{0}C is found.</td></tr>
<tr><td>6.</td><td>Optimal ambient temperature envelope</td><td colspan="6">35-40 ^{0}C. Drone spraying above 40 ^{0}C results in excessive vapour drift causes low bio-efficacy.</td></tr>
<tr><td>7.</td><td>Time for Drone spraying</td><td colspan="6">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).</td></tr>
<tr><td>8.</td><td>Field Capacity of recommended 10L payload spraying drone</td><td colspan="6">2.43 ha hr^{-1}</td></tr>
</table>

Bio-efficacy studies

During *kharif* 2021, the pre-treatment population of leafhoppers was uniform and non-significant among treatments with their highest peak of 16.62 to 17.00 leafhopper population per 3 leaves per plant. Leafhopper population after 3 days after spraying recorded was 3.50 per three leaves, 5.02 per three leaves in 100% RDP and 75% RDP, respectively with UAV and with 78.57% and 70.09% reduction over control which were on par with each other. The treatment with 100% RDP human back sprayer showed 7.05 leafhopper per 3 leaves with 58.04% reduction over control. The treatment 50% RDP with UAV had 9.25 leafhoppers per three leaves with 44.34% reduction while, 16.8 leafhoppers per three leaves in control was noticed.

At five days after spraying, mean number of 5.00 and 6.10 leafhoppers in 100% and 75% RDP with 71.10 and 64.74 per cent reduction over control were recorded and were at par with each other. Insecticide spray with human back motorized sprayer recorded an average of 7.62 leafhoppers per three leaves with 55.92% reduction and 50% recommended dosage with UAV showed 10.12 leafhoppers per three leaves with 41.47% reduction and in control 17.3 leafhoppers per three leaves per plant were observed.

At seven days after spray, 6.87 and 7.70 leafhoppers per three leaves in 100% RDP and 75% with UAV and 60.14%, 55.36% reduction, respectively, were noticed and were on par with each other. Human back motorized spraying recorded an average of 8.75 leafhoppers per three leaves with 49.28% reduction over control and in treatment with 50% RDP with UAV about 11.25 leafhoppers per three leaves with 34.78% reduction over control were noticed. Untreated plot had 17.25 leafhoppers per three leaves per plant as presented in Table 5.

During *kharif* 2022, the pre-treatment population of leafhoppers was in the range of 13.75 to 14.75 leafhoppers per three leaves with their highest peaks in season. Mean data on leafhopper after three days of spraying was 2.62, 3.65 leafhoppers per three leaves in 100% RDP & 75% RDP with UAV and 82.79%, 76.07% reduction over control, respectively. Treatments with 100% dosage with human back motorized sprayer recorded 6.00 leafhoppers with 60.66 % reduction. Treatments with 50% recommended dosage with drone recorded 10.5 leafhoppers per three leaves with 31.15% reduction and untreated plot had 15.25 leafhopper per three leaves.

After five days after spraying, mean of 4.75 and 5.12 leafhoppers per three leaves in 100%, 75% RDP with drone and 69.35 and 66.94% reduction were recorded and however these were on par with each other. Human back knapsack spraying showed an average of 7.25 leafhoppers per three leaves with 53.23% reduction and 50% recommended dosage with drone showed 12.25 leafhoppers per three leaves with 20.97% reduction and untreated plot was with 15.5 leafhopper per three leaves/plant as presented in Figure 3.

At 7 days after spraying, reduction was observed in the same trend with 5.12, 5.37 leafhoppers per three leaves in 100% RDP and 75% RDP with drone and 66.94% and 65.32% reduction which were at par with each other and this was followed by good efficacy in human spraying with an average of 8.95 leafhoppers per three leaves with 42.26% reduction and 50% recommended dosage with drone showed 13.25 leafhoppers per three leaves with 14.52 % reduction over control and 18.75 leafhoppers per three leaves per plant was noticed in untreated plot as presented in Table 6.

These findings are in line with Santhoshi *et al*. (2022) who reported that Flonicamid 50% WG as the best treatment against leafhopper with 96.99% reduction at three days after spraying and 89.62% in seven days after spraying. Nemade *et al*. (2015) reported flonicamid 50% WG @ 75 g a.i. ha^{-1} to be promising to manage sucking pest in cotton and leafhopper with 88.20% reduction over control at three days after first spray. Ghelani *et al*. (2014) mentioned 78.4 per cent mortality and 72.8 mortality at three and five days after spraying, respectively, with flonicamid 50% WDG. This is in coherence with Qiu *et al*. (2013) research on wheat pest control with UAV spraying that showed the control efficacy of 92% –74% at 3 to 10 days with good control effect and long persistence. Jagadish and Paradkar (2020) reported the minimum population (6.57) was found in the treatment with Flonicamid 50% WG @ 150 g/ ha which is significantly superior over rest of the treatments during first spray than another treatments.

Phytotoxicity

The data regarding phytotoxic effects such as chlorosis, necrosis, epinasty, hyponasty, wilting and scorching at 1, 3 and 5 days after spraying revealed that Flonicamid 50% WG @ 150 gm ha^{-1} at 50%, 75% and 100 % recommended dose sprayed with UAV and 100 % recommended dose with human back power sprayer did not show any phytotoxicity in cotton even up to harvesting. High NDVI values (Tables 5 & 6) were recorded in the treatments T1. T2, T3 and T4 after 7 days after spraying *i.e.* 0.75,0.73,0.74 and 0.69, respectively, in *kharif* 2021 and 0.76,0.74,0.75 and 0.67, respectively, in *kharif* 2022 indicating the healthy crop growth and no phytotoxicity in the plant canopy.

UAV spraying to control *Amarasca biguttula biguttula* was found effective and efficient in managing the pest, utilizing the pesticide substance delivery and deposition when compared to human backpack spraying. The recommended dosage of insecticide for UAV spraying to control leafhoppers for the CIB & RC recommended insecticide Flonicamid 50% WG is found to be 75% RDP i.e. 90 gm $acre^{-1}$ instead of 120 ml $acre^{-1}$ which is also found effective in controlling leafhopper in cotton.

Table 5 Efficacy of flonicamid 50 % WG on leafhopper *Amarasca biguttula biguttula* in cotton using kisan drone and NDVI values in *kharif* 2021

Treatment details	Number of leafhopper (nymph + adult) per Top 3 leaves							
	1 DBSP	3 DASP	ROC	5 DASP	ROC	7 DASP	ROC	NDVI value at 7 DASP
T1	16.62	3.5 (2.14) [a]	78.57	5.00 (2.45) [a]	71.10	6.87 (2.80) [a]	60.14	0.76
T2	16.75	5.02 (2.45) [a]	70.09	6.10 (2.66) [a]	64.74	7.7 (2.94) [a]	55.36	0.75
T3	17.00	9.25 (3.20) [c]	44.34	10.12 (3.33) [c]	41.47	11.25 (3.50) [c]	34.78	0.73
T4	17.00	7.05 (9.75) [b]	58.04	7.62 (2.93) [b]	55.92	8.75 (3.12) [b]	49.28	0.74
T5	16.8	16.8 (4.21)	0.00	17.3 (4.27)	0.00	17.25 (4.27)	0.00	0.69
CD	NA	0.37		0.275		0.33		
CV (%)	5.726	8.06		5.63		6.49		

DBSP-Day before Spraying; DASP-Days after Spraying; ROC-Reduction over control; NDVI- Normalized Difference Vegetation Index

Table 6: Efficacy of flonicamid 50 % WG on leafhopper *Amarasca biguttula biguttula* in cotton using kisan drone and NDVI values in *kharif*, 2022

Treatment details	Number of leaf hopper (nymph + adult) per Top 3 leaves							
	1 DBSP	3 DASP	ROC	5 DASP	ROC	7 DASP	ROC	NDVI value at 7 DASP
T1	13.75	2.62 (1.90) a	82.79	4.75 (2.39) a	69.35	5.12 (5.37) a	66.94	0.77
T2	14.75	3.65 (2.15) a	76.07	5.12 (2.47) a	66.94	5.37 (2.52) a	65.32	0.76
T3	13.75	10.5 (3.39) c	31.15	12.25 (3.64) c	20.97	13.25 (3.77) c	14.52	0.74
T4	14.5	6.00 (2.64) b	60.66	7.25 (2.87) b	53.23	8.95 (3.15) b	42.26	0.75
T5	14.75	15.25 (4.03)	0.00	15.5 (4.06)	0.00	18.75 (4.44)	0.00	0.67
CD	NA	0.37		0.32		0.37		
CV (%)	5.726	8.06		6.65		7.42		

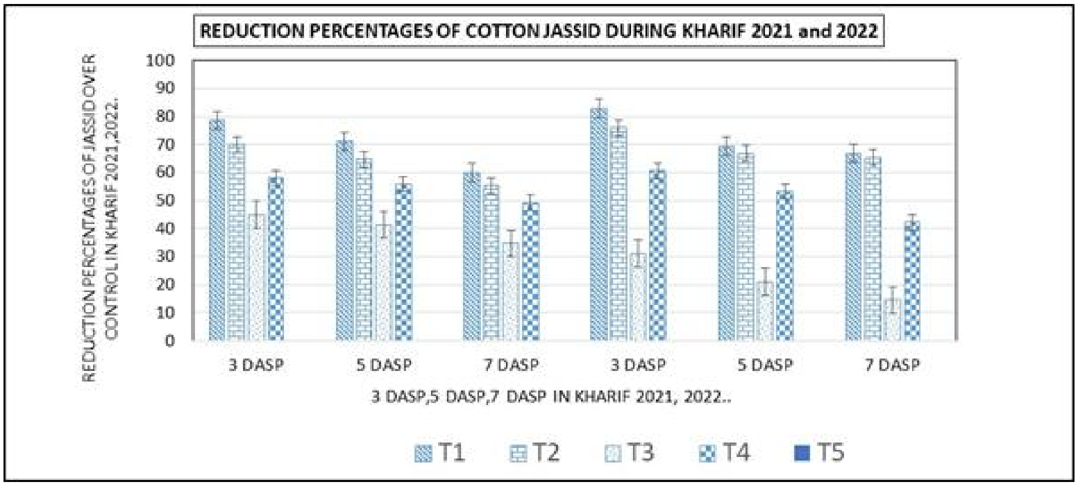


Figure 3 Reduction Percentage over control (ROC) in cotton leafhopper during *kharif* 2021, 2022

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