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Effect of the Drone and Knapsack Sprayed Herbicides on the Plant Phytotoxicity and Chlorophyll Content in *Rabi* Groundnut

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Conventional method of herbicide spray application using a knapsack sprayer is cost-effective, easy to operate but leads to inaccurate application of the chemicals, low spray uniformity, unnecessary deposition and non-uniform coverage. In this context, "Unmanned aerial vehicles (UAVs), or aerial drones, are being utilized to decrease the herbicide wastage and increase the efficacy compared to traditional practice. A two year field experiment was conducted with drone at RARS, Research

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Farm, Palem, Nagarkurnool, Telangana during *rabi* 2022-23, 2023-24.The model of UAV (drone) used in the bioefficacy and drift studies was battery motive AGRICOPTER AG 365 with UIN UA00132S1EX. Imazethapyr 3.75% + Propaquizafop 2.5% ME (Ready mix) herbicide was sprayed with 25 and 40 L ha^{-1} of spray volume with flat fan XR11002VP nozzle and flight height was maintained at 2 and 2.5m and knapsack sprayer with 500 L ha^{-1} of spray volume was taken to study the effect of the drone sprayed herbicides versus conventional spraying practices on plant phytotoxic and chlorophyll content of the leaves and results had shown a non significant effect on chlorophyll content and phytotoxicity.

Keywords: Unmanned aerial vehicle; Shaked; XR11002VP; phytotoxicity; chlorophyll content.

1. INTRODUCTION

Among the oilseed crops, groundnut is the 4th most predominant oilseed crop and 13th crucial food crop of the world. The groundnut seed contains 47-53% oil and 26% protein and 11.5% starch. It is grown in almost all the tropical and sub-tropical countries. China and India are the huge producers of groundnut, accounting for 41% and 18% of total world's production, respectively (Mishra et al*.* 2016). According to the all India *rabi* crop coverage report, Government of India, as on 2024, groundnut was sown in around 4.88 lakh hectares as compared to 2023 (5.68 lakh ha). Among the states, Karnataka stood first in area coverage with (1.11 lakh ha) followed by Odisha (1.00 lakh ha), Telangana (0.84 lakh ha). In Telangana, groundnut has been sown in around (84961.72 ha) as on 2024 compared to 2023 (98250 ha) (Groundnut outlook, 2024). Among the districts, Nagarkurnool stood first in groundnut sown area with (42294.91 ha) followed by Wanaparthy (8614.13 ha) (www.agri.telangana.gov.in).

Herbicides are selective, cost-effective, easy to apply, and offer flexibility in terms of application timing. While they have greatly contributed to increasing crop yields, their use is not free from potential environmental problems such as soil persistence, groundwater pollution, toxic residues in food, feed, and fodder, adverse impacts on non-target organisms, and the development of resistance in weeds (NRCWS 2007).

One of the most effective herbicides for groundnut in India is imazethapyr [5-ethyl-2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl) nicotinic acid]. Imazethapyr (Aceto Lactate Synthase inhibitor, ALS inhibitor) has both soil and foliar activity and is absorbed through roots and foliage and translocated in both xylem and phloem and there by accumulated in plants at growing points. Propaquizafop (2-isopropylideneamino-oxyethyl (R)-2- [4-(6-chloroquinoxalin-2-yloxy) phenoxy] propionate) is used as a selective, post-emergence phenoxy herbicide. It is Acetyl Co-enzyme-A inhibitor (ACC Inhibitor) and control grass weeds in groundnut crop (Stougaard et al*.,* 1990). Of late, a ready-mix herbicide combination product of Imazethapyr and propaquizafop was registered in India.

Imazethapyr and propaquizafop may be injurious to the non target plant species and its residue is known to persist in the soil affecting the succeeding crop. Application with knapsack sprayer utilizes large quantities of water (spray volume 500 Lha^{-1}), spray application may not be uniform, and exposes the herbicide applicator to the toxic chemicals. Recently, drones are being tested in many agronomic operations mainly application of herbicides due to its low spray volume with low water content and high concentration of the herbicide and high coverage (Ambarish et al., 2017; Ambarish et al., 2017).

In earlier field studies conducted by several researches, herbicides caused injury to crops and severity of injury increased with rate of application. It has been reported that an increase in the concentration of imazethapyr significantly reduced the growth of primary root meristems, fresh and dry weight, yield, and the number of root nodules under field conditions (Gaston et al*.* 2002).

UAVs can substantially manage a variety of pests and diseases by adjusting the application parameters. The loss of weedicides and reduced effectiveness of weed management techniques can result from higher spray volume. In addition, none of the previous research studies looked at how different UAV water spray volumes affect the ability to control weeds in groundnut fields. Accordingly, based on the results of the available studies, it is unknown how effectively the low-water-consumption spray used by the UAV will suppress weeds. The application of herbicide using drones involves very low spray volumes, typically ranging from 20 to 60 litres per hectare. However, most herbicides registered in India are formulated for application with spray volumes of 300-500 liters per hectare. Consequently, using very low spray volume increases the concentration of the herbicide's active ingredient and other chemical additives (added for formulation stability and shelf life) in the spray fluid.

As the chemical (herbicide and additive) concentration increases droplet, the smaller droplet size and reduced coverage area on the leaf surface can enhance the likelihood of phytotoxicity or scorching effects on crop foliage. This study investigates the application of recommended herbicides at three dose levels and two spray volumes and aims to evaluate their impact on groundnut foliage. Phytotoxic effects will be assessed through both visual observations and SPAD readings to provide a comprehensive understanding of the herbicide's influence on the crop.

2. MATERIALS AND METHODS

A two years field experiment was conducted at RARS Research Farm, Palem, Nagarkurnool, Telangana during *rabi* season of 2022-23, 2023-24 years. Experimental field is situated at 16˚3'0"North Latitude and 78˚14'5"East Longitude. The soil of the experimental field in the two years was sandy loam in texture.

The model of UAV (drone) used in the bioefficacy and drift studies was battery motive AGRICOPTER AG 365 with UIN UA00132S1EX. The flight speed was adjusted to 2.0 - 2.5m/s and the capacity of the tank was 10 L. The interval of nozzles was 30 cm and four nozzles were arranged in total length of 1.20 m with an installation angle was 110^0. Herbicides was sprayed with 25 and 40 L ha^{-1} of spray volume with flat fan XR11002VP nozzle. The flight height was maintained at 2.0 and 2.5 m and effective spraying swath for treatments was adjusted to 4.0 m. The knapsack sprayer with tank capacity of 10 L ha^{-1} with spray volume of 500 L ha^{-1} was taken.

A post-emergence herbicide containing combination of imazethapyr 3.75% + propaquizafop 2.5% ME (Ready mix) was applied to the groundnut crop. The herbicide was tested at 3 levels *viz*., 75%, 100% and 125% of the recommended. A total of 17 treatments with (12 UAV +5 checks) were tested as mentioned in Table 1.

The design opted was 3X2X2 Factorial RBD with 12 treatments of UAV and 5 treatments as a checks (outsidethe layout) and all these treatments were replicated thrice.

Factor 1: Herbicide Doses:3; Herbicide combination: Imazethapyr 3.75% + Propaquizafop 2.5% ME (Ready mix). D1: 75% recommended dose (56.25 g ha-1 + 37.5 g ha^{-1}) (0.75 X), D2: 100% recommended dose (75 g ha-1 + 50 g ha^{-1}) (X), D3: 125% recommended dose (93.75 g ha-1+ 62.5 g ha^{-1}) (1.25X) . Spray fluid volume: 2, S1: 25 litres ha^{-1}, S2: 40 litres ha^{-1}.Factor 3: Height of spray: 2, H1: 2.0 m above the crop canopy , H2: 2.5 m above the crop canopy Checks: 5, 1. Manual spray of 75% Recommended dose (56.25 g ha-1 + 37.5 g ha-1) (0.75 X) with Knapsack sprayer, 2. Manual spray of100% Recommended dose (75 g ha-1 + 50 g ha-1) (X)) with Knapsack sprayer ,3. Manual spray of 125% recommended dose (93.75 g ha-1+ 62.5 g ha-1) (1.25X)) with Knapsack sprayer ,4. Unweeded check ,5. Weed Free check (Manual weeding at 20, 40, 60 DAS).

Groundnut variety K-6, a bunch type released from Agricultural Research Station, Kadiri, ANGRAU was used as test variety. The duration of the variety is 120 days. The crop was supplied with fertilizers (20 kg N, 40 kg P_2O_5 and 50 kg K_2O) as per the recommendation of PJTAU, in the form of urea, single super phosphate and muriate of potash respectively to all the plots.

2.1 Plant Phytotoxicity

Phytotoxicity assessment in crop was done by visual assessment of plants in each treatment at 7, 10 days after application of herbicide. The extent of phytotoxicity was recorded based on scale of Central Insecticide Board and Registrtaion Committee (CIB& RC).

2.2 Chlorophyll Content of the Leaves

The mean of three readings from a portable Minolta chlorophyll meter SPAD 502 (Spectrum Technologies, Inc., Plainfield, IL, U.S.) was obtained for each leaf disc from individual leaves. The leaf disc used to obtain a SPAD value provided sufficient tissue for total chlorophyll at 7 and 10 DAA.

Table 1. Treatment details of the experimental field

Treatment	Treatment Details
T_1	75% Recommended dose (56.25 g ha^{-1} + 37.5 g ha^{-1}) with spray volume 25 L ha^{-1} and spray height 2m above the crop canopy (0.75 X).
T_2	75% Recommended dose (56.25 g ha^{-1} + 37.5 g ha^{-1}) with spray volume 25 L ha^{-1} and spray height 2.5m above the crop canopy (0.75 X).
T_3	75% Recommended dose (56.25 g ha^{-1} + 37.5 g ha^{-1}) with spray volume 40 L ha^{-1} and spray height 2m above the crop canopy (0.75 X)
T_4	75% Recommended dose (56.25 g ha^{-1} + 37.5 g ha^{-1}) with spray volume 40 L ha^{-1} and spray height 2.5m above the crop canopy (0.75 X)
T_5	100% recommended dose (75 g ha^{-1} + 50 g ha^{-1}) with spray volume 25 L ha^{-1} and spray height 2m above the crop canopy(X)
T_6	100% recommended dose (75 g ha^{-1} + 50 g ha^{-1}) with spray volume 25 L ha^{-1} and spray height 2.5 m above the crop canopy (X)
T_7	100% recommended dose (75 g ha^{-1} + 50 g ha^{-1}) with spray volume 40 L ha^{-1} and spray height 2m above the crop canopy(X)
T_8	100% recommended dose (75 g ha^{-1} + 50 g ha^{-1}) with spray volume 40 L ha^{-1} and spray height 2.5 m above the crop canopy (X)
T_9	125% recommended dose (93.75 g ha^{-1}+ 62.5 g ha^{-1}) with spray volume 25 L ha^{-1} and spray height 2m above the crop canopy (1.25X)
T_{10}	125% recommended dose (93.75 g ha^{-1}+ 62.5 g ha^{-1}) with spray volume 25 L ha^{-1} and spray height 2.5m above the crop canopy (1.25X)
T_{11}	125% recommended dose (93.75 g ha^{-1}+ 62.5 g ha^{-1}) with spray volume 40 L ha^{-1} and spray height 2m above the crop canopy (1.25X)
T_{12}	125% recommended dose (93.75 g ha^{-1}+ 62.5 g ha^{-1}) with spray volume 40 L ha^{-1} and spray height 2.5m above the crop canopy (1.25X)
T_{13}	775% Recommended dose (56.25 g ha^{-1} + 37.5 g ha^{-1}) with Knapsack sprayer (0.75 X)
T_{14}	O100% Recommended dose (75 g ha^{-1}+ 50 g ha^{-1}) with Knapsack sprayer (X))
T_{15}	1125% recommended dose (93.75 g ha^{-1}+ 62.5 g ha^{-1}) with Knapsack sprayer (1.25X)
T_{16}	Un weeded check, control (C)
T_{17}	Weed Free check, (Manual weeding at 20, 40, 60 DAS) (WF)

Table 2. Phyto-toxicity scoring of crop

Ratings	% of injury	Verbal description
1	0	No injury, no reduction in crop plant number
2	1-3.5	Slight discolouration in crop
3	3.5-7	Moderate but not lasting damage
4	7-12.5	Moderate and more lasting, they need more time to recover
5	12.5-20	Medium and lasting
6	20-30	Heavy damage
7	30-50	Very heavy reduction in crop stand
8	50-90	Nearly destroyed
9	100	Completely destroyed

Rao VS (2002)

3. RESULTS AND DISCUSSION

Effect of the UAV (drone) and knapsack sprayed herbicides on the plant Phytotoxicity in groundnut: The application of Imazethapyr and Propaquizafop as post-emergence treatments at 0.75X, 1.0X, and 1.25X doses, using 25 and 40 L ha^{-1} spray volumes at heights of 2 m and 2.5 m with UAVs (drones), along with the application of 0.75X, 1.0X, and 1.25X doses using a knapsack sprayer, and their effects on plant phytotoxicity are presented in Tables 3 and 4. In 2022-23, plots treated with herbicides exhibited stunted growth and yellowing of new leaves at 7 and 10 days after application. However, the crop fully recovered by 14 days after application. The most pronounced stunted growth and leaf yellowing were observed with the 1.25X rate of application.

Compared to the knapsack sprayer (phytotoxicity score of 2), phytotoxicity symptoms observed with drone spraying were significantly lower, with scores of less than 1. In the lower application rate (0.75X), fewer than 10% of plants exhibited phytotoxicity, with a score of 0. During the 2023-24 season, stunted growth and yellowing of groundnut leaves were more pronounced with the 1.25X application using the knapsack sprayer compared to drone spraying. Herbicide applications at the recommended rate and 75% of the recommended rate did not result in any phytotoxicity symptoms.

In contrast, plants treated with 0.75X and 1.0X doses using the knapsack sprayer displayed phytotoxic symptoms, including yellowing of leaves and vein discoloration. This could be attributed to the higher herbicide exposure with the knapsack sprayer compared to the drone spray, leading to the inhibition of amino acid synthesis, which disrupts the production of chlorophyll and other essential compounds necessary for healthy plant growth, ultimately causing chlorosis (yellowing) of the leaves.

Table 3. Visual observations on phytotoxicity (score: 0 to 10) in groundnut at 7 and 10 days after herbicide application of imazethapyr and propaquizafop with UAV and knapsack sprayer in 2022-23.

Trt No.	Details	2022-23					
		7 DAA			10 DAA		
T_1	$D_1S_1H_1$	0	0	0	0	0	0
T_2	$D_1S_1H_2$	0	0	0	0	0	0
T_3	$D_1S_2H_1$	0	0	0	0	0	0
T_4	$D_1S_2H_2$	0	0	0	0	0	0
T_5	$D_2S_1H_1$	0	0	0	0	0	0
T_6	$D_2S_1H_2$	0	0	0	0	0	0
T_7	$D_2S_2H_1$	0	0	0	0	0	0
T_8	$D_2S_2H_2$	0	0	0	0	0	0
T_9	$D_3S_1H_1$	0	1	0	0	0	0
T_{10}	$D_3S_1H_2$	0	1	0	0	0	0
T_{11}	$D_3S_2H_1$	0	1	0	0	1	0
T_{12}	$D_3S_2H_2$	0	1	0	0	1	0
T_{13}	$KS_{(0.75x)}$	0	1	0	0	1	0
T_{14}	$KS_{(1x)}$	0	1	1	0	1	0
T_{15}	$KS_{(1.25x)}$	0	1	2	0	1	1

Table 4. Visual observations on phytotoxicity (score: 0 to 10) in groundnut at 7 and 10 days after herbicide application of imazethapyr and propaquizafop with UAV and knapsack sprayer in 2023-24

Trt No.	Details	2023-24					
		7 DAA			10 DAA		
T_1	$D_1S_1H_1$	0	0	0	0	0	0
T_2	$D_1S_1H_2$	0	0	0	0	0	0
T_3	$D_1S_2H_1$	0	0	0	0	0	0
T_4	$D_1S_2H_2$	0	0	0	0	0	0
T_5	$D_2S_1H_1$	0	0	0	0	0	0
T_6	$D_2S_1H_2$	0	0	0	0	0	0
T_7	$D_2S_2H_1$	0	0	0	0	0	0
T_8	$D_2S_2H_2$	0	0	0	0	0	0
T_9	$D_3S_1H_1$	0	0	0	0	0	1
T_{10}	$D_3S_1H_2$	0	0	0	0	0	0
T_{11}	$D_3S_2H_1$	0	1	0	0	1	0
T_{12}	$D_3S_2H_2$	0	1	0	0	1	0
T_{13}	$KS_{(0.75x)}$	0	1	0	0	0	0
T_{14}	$KS_{(1x)}$	0	1	1	0	1	0
T_{15}	$KS_{(1.25x)}$	0	2	1	0	1	1

Table 5. Effect of the UAV sprayed herbicides on the SPAD readings in 2022-23 and 2023-24

Trt No.	Details	2022-23		2023-24	
		7DAA	10DAA	7DAA	10DAA
T_1	$D_1S_1H_1$	32.94	37.93	35.07	37.93
T_2	$D_1S_1H_2$	33.33	40.44	35.33	40.72
T_3	$D_1S_2H_1$	32.88	39.21	35.06	39.21
T_4	$D_1S_2H_2$	33.44	38.86	35.83	38.86
T_5	$D_2S_1H_1$	32.58	40.05	34.76	39.12
T_6	$D_2S_1H_2$	32.18	38.36	34.67	37.70
T_7	$D_2S_2H_1$	32.40	40.40	35.20	37.46
T_8	$D_2S_2H_2$	32.70	37.46	35.46	37.43
T_9	$D_3S_1H_1$	32.24	36.70	34.63	37.13
T_{10}	$D_3S_1H_2$	32.50	37.21	34.83	37.33
T_{11}	$D_3S_2H_1$	32.29	35.02	34.76	37.55
T_{12}	$D_3S_2H_2$	31.91	34.11	34.41	36.56
T_{13}	$KS_{(0.75x)}$	31.30	38.28	33.96	36.32
T_{14}	$KS_{(1x)}$	30.03	36.70	33.16	35.83
T_{15}	$KS_{(1.25x)}$	29.80	36.37	33.03	35.76
T_{16}	C	34.69	39.67	36.33	40.31
T_{17}	WF	34.85	42.29	38.40	42.85
SE(m)		**1.7**	**2.0**	**1.8**	**2.5**
CD		**NS**	**NS**	**NS**	**NS**

These results align closely with the findings of Patel (2012), who reported no phytotoxicity in black gram but observed stunted growth when imazethapyr was applied post-emergence at 100 g ha^{-1}. Similar observations were made by Jitendra et al*.* (2022), who reported reduced leaf area and stunted growth in groundnut with the application of acifluorfen + clodinafop propargyl and fomesafen + fluazifop-p-butyl. Brahmbhatt (2014) also documented comparable outcomes in blackgram.

Effect of the UAV and knapsack sprayed herbicides on the chlorophyll content in groundnut: Weed management in groundnut using imazethapyr and propaquizafop had no significant impact on the chlorophyll content, as presented in Table 5. In 2022-23, the chlorophyll content measuredat 7 days after application DAA ranged from 29.80 to 34.69, with highest SPAD value of 34.69 recorded in the weed-free plots and the lowest with 29.80, observed in the knapsack sprayer treatment at the 1.25X dose.

Among drone-applied treatments, SPAD readings ranged from 31.91 (T_{12}, 1.25X dose) to 33.44 (T_4, 0.75X dose).

A variation in SPAD readings was evident across herbicide doses. For knapsack sprayer treatments, the SPAD value was 31.30 for the 0.75X dose and 29.80 for the 1.25X dose. At 10 DAA, SPAD readings ranged from 36.37 to 42.29, with the highest value recorded in the weed-free plots (42.29) and the lowest in the knapsack sprayer treatment at the 1.25X dose (36.37). Among drone treatments, the highest SPAD value (40.44) was observed in T_2, while the lowest (34.11) was seen in T_{12}. Knapsack sprayer treatments showed a higher SPAD value at the 0.75X dose (38.28) compared to the 1.25X dose (36.37).

In 2023-24, SPAD readings at 7 DAA ranged from 33.03 (knapsack sprayer, 1.25X dose) to 38.40 (weed-free plots). For drone-applied treatments, SPAD values varied between 34.41 (T12, 1.25X dose) and 35.83 (T4, 0.75X dose). Compared to drone applications, knapsack sprayer treatments recorded lower SPAD values, with the 0.75X dose showing 33.96 and the 1.25X dose showing 33.03. At 10 DAA, SPAD readings ranged from 35.76 to 42.85, with the weed-free plots recording the highest value (42.85) and the knapsack sprayer treatment at the 1.25X dose showing the lowest (35.76). Drone treatments recorded SPAD values ranging from 36.56 (T_{12}) to 40.72 (T_2), while knapsack treatments ranged from 35.76 (1.25X dose) to 36.32 (0.75X dose).

These results indicate that the highest SPAD values were consistently observed at the 0.75X dose applied via drone spraying. An increase in herbicide concentration resulted in reduced chlorophyll content and SPAD values, likely due to leaf yellowing caused by higher herbicide concentrations. These findings align with those of Sudharshana et al. (2014), who reported lower SCMR values when imazethapyr was applied at 150 g a.i. ha^{-1}, and Shobha and Manijeh (2011), who observed a negative correlation between herbicide concentration and chlorophyll content at higher doses, such as 10 ppm.

4. CONCLUSION

It can be concluded that higher concentration of imazethapyr and Propaquizafop resulted in a reduction of leaf chlorophyll content in groundnut, leading to yellowing of the leaves. This, in turn, decreased the plant's photosynthetic activity and adversely affected the crop growth.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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