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EVALUATION OF DRONE-APPLIED POST-EMERGENCE HERBICIDES ON WEED MANAGEMENT AND GRAIN YIELD IN TRANSPLANTED RICE (*ORYZA SATIVA* L.)

Lakavath Naveen[1]*, P. Spandana Bhatt[2], K. Bhanu Rekha[1] and T. Ramprakash[4]
[1] College of Agriculture, PJTSAU, Rajendranagar, Hyderabad, Telangana, India.
[2]Institute of Rice Research, Rajendranagar, Hyderabad, India.
[3]AICRP on Weed Management (DJB), Rajendranagar, Hyderabad, India.
*Corresponding author E- mail: naveenlakavath1998@gmail.com
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ABSTRACT

A field experiment was conducted at Rice Research Centre, Agriculture Research Institute, Rajendranagar, Hyderabad during *kharif,* (2022) to assess the post emergence herbicide efficacy for drone spraying in transplanted rice (*Oryza sativa* L.). The experiment was laid out in randomized block design with 7 treatments and replicated thrice. Results revealed that lower weed density, weed dry matter, lower nutrient removal by weeds and higher grain yield were noticed with hand weeding at 20, 40 and 60 DAT followed by application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone and it was statistically on par with application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer, application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone and application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone followed by application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone followed by unweeded control. The lower weed density, weed dry matter and higher grain yield were recorded in Hand weeding at 20,40 and 60 DAT.
***Keywords*:** Unmanned Aerial Vehicle, Drone, Herbicide efficacy, transplanted rice.

Introduction

Rice (*Oryza sativa* L.) is global grain as it is the most cultivated and consumed grain on the planet, the staple diet of billions of people and provides 70% direct employment to the rural India (Saha *et al*. 2017). Rice is one of the most widely consumed grains in the world. As the most populous country in the world, China also consumes more rice than any other country, with about 155 million metric tons consumed in 2022/2023. Following China, India is ranked second with 108.5 million metric tons of rice consumed in the same period (Rice consumption worldwide in 2022/2023, by country in 1,000 metric tons). In the 2021/2022 crop year, China produced over 148 million metric tons of milled rice, a higher volume than any other country. India came in second place with over 129 million metric tons of milled rice in that crop year. The estimated total volume of milled rice produced worldwide reached over 502 million metric tons in the 2022-2023 crop year (www.statista.com, 2022-2023).

Rice crop suffers from various biotic and abiotic constraints. Weeds are one of the major yield limiting factors among biotic constraints in rice. Weeds compete with the crop plants for nutrients, moisture and sunlight. (Kumar *et al.* 2010) reported that the reduction in grain yield of rice due to uncontrolled weeds in the weedy plot was 70.4 % during 2006 and 67.4 % during 2007 as compared to weed control treatments. Grassy weeds were heavy competitors with rice crop followed by sedges and broadleaved weeds.

A Drone (Unmanned Aerial Vehicle) is essentially flying ROBOT remotely controlled through software-controlled flight plans in their embedded system working in conjunction with onboard SENSORS and GPS (Global Positioning System). Due to high adaptability of UAV platforms makes them viable alternative for aerial pesticide application (Wang *et al.* 2018). Unmanned Aerial Vehicles (UAV) were initially designed for military purposes, but the rapid development of efficient technologies such as sensors, global positioning systems (GPS), and civilian-accessible computers has expanded the potential of drones for various applications (Ehsani and Maja 2013; Hogan *et al.* 2017). Drones are a potential alternative for aerial chemical spraying due to their high adaptability (Wang *et al.* 2018). Drones can help farmers to save time by assist in a variety of ways, including soil fertilization, spraying, irrigation, crop health monitoring, planting and herd tracking. It is possible to work in dampy or sloping environments, reduce work load and application in specific locations is also possible.

Materials and Methods

A field experiment was conducted at Rice Research Centre, Agriculture Research Institute, Rajendranagar, Hyderabad during *Kharif,* (2022). On clay loam soil neutral in nature (pH 7.6), having EC 0.71dSm^{-1}, organic carbon (0.45%) and available nitrogen (212 kg ha^{-1}), phosphorus (28.2 kg ha^{-1}) and potassium (452.6 kg ha^{-1}). The experiment was laid out in randomized block design with 7 treatments and replicated thrice. Rice variety RNR-15048 was sown with a seed rate of 50 kg ha^{-1}, maintaining 15 cm x 15 cm with two seedlings per hill. For transplanted rice was 120:60:40 kg N, P_2O_5, K_2O respectively which was supplied to crop through urea, single super phosphate and muriate of potash. Entire dose of phosphorous was applied as basal dose. Whereas, nitrogen was applied in three equal splits at transplanting, maximum tillering stage and at panicle initiation stage. The recommended potash was applied in two equal splits at transplanting and panicle initiation stage of rice. Pre-emergence (PE) application of herbicides was done at 3 days after transplanting (DAT) and post-emergence (PoE) at 30 DAT using 500 liters of water/ha as spray fluid with flat fan nozzle fitted knapsack sprayer and 40 liters of water ha^{-1} using drone. The observations on plant height (cm), number of tillers (m^{-2}), number of panicles (m^{-2}) at harvest, grain yield (kg ha^{-1}) and weed dry matter at 60 DAT.

Table 1 : Details of the treatments

Treatment No.	Treatment details
T_1	Application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1}using knapsack sprayer.
T_2	Application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone.
T_3	Application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1}using drone.
T_4	Application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1}using drone.
T_5	Application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1}using drone.
T_6	Weed free (Hand weeding at 20, 40 and 60 DAT)
T_7	Unweeded control

Data pertaining to effect of different weed management practices on total grass weed density was recorded. Data recorded at 20 DAT was initial count *i.e*., before treatment imposition. Data recorded at 40, 60, 80 DAT and at harvest were recorded after treatment imposition, analyzed statistically and presented in Table.1.

Results and Discussion

Effect on weeds

Total grass weed density

Data pertaining to effect of different weed management practices on total grass weed density was recorded. Data recorded at 20 DAT was initial count *i.e*., before treatment imposition. Data recorded at 40, 60, 80 DAT and at harvest were recorded after treatment imposition, analyzed statistically and presented in Table.2.

At 20 DAT, significantly lower grass weed density was recorded with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.00) followed by T_2 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (3.61) and T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (3.61), which were statistically on par with T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (3.70), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.87) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.94).

Significantly higher total grass weed density was recorded with T_7 (unweeded control) (4.91).

At 40 DAT, significantly lower grass weed density was observed with the T_6 (weed free hand weeding at 20, 40 and 60 DAT) (1.97) which was statistically on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (2.41) and T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (2.45) followed by T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (2.53) which was on par with T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (2.88) which was inturn on par with T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.21). Significantly higher total grass weed density was recorded with T_7 (unweeded control) (6.05). There was decrease in weed density after the application of post emergence herbicide either by using knapsack sprayer as well as by deploying drone. Similar finding was reported by supriya *et al*. (2021) reported in maize crop.

At 60 DAT, significantly lower grass weed density was observed with the T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.32) followed by T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (2.95) which was statistically on par with T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (2.98), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.08) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.18) further followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (3.81). Significantly higher grass weed density was recorded with T_7 (unweeded control) (7.68).

At 80 DAT, significantly lower grass weed density was observed with the T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.45) it was statistically on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (2.95), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (2.95), T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (3.08) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.19) followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (3.95). Significantly higher total grass weed density was recorded withT_7 (unweeded control) (7.36).

At harvest significantly lower grass weed density was observed with the T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.30) which was statistically on par with T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (2.74), T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (2.77) and T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (3.07). Followed by T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.18) and was statistically on par with T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (3.69). Significantly higher grass weed density was recorded with T_7 (unweeded control) (6.91). Pre-mix herbicides with different mode of action have ability to control broad spectrum of weeds over single herbicides. These results were in tune with Devigegan *et al*. (2017) and Ramesha *et al*. (2019).

Total sedge weed density

Data pertaining to effect of different weed management practices on total sedge weed density was recorded at 20 DAT (initial count *i.e.,* before treatment imposition), data recorded at 40, 60, 80 DAT and at harvest were recorded after treatment imposition, was analysed statistically and presented in Table 3.

At 20 DAT, significantly lower total sedge weed density was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (1.61), followed by T_5 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (3.51) and was statistically on par with rest of the treatments *i.e.,* T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.61), T_4 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (3.63), T_3 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.71) and T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (3.71) except T_7 (unweeded control) which recorded significantly higher total sedge weed density (5.07).

At 40 DAT, significantly lower sedge weed density was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.05), followed by T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (3.03) and was statistically on par with T_1 (application of penoxsulam1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.00), T_4 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (3.21) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.35), followed by T_2 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (3.67). Significantly higher to total sedge weed density was recorded with T_7 (unweeded control) (6.27). Similar finding was reported by Supriya *et al*. (2021) in maize crop.

At 60 DAT, significantly lower sedge weed density was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.47) which was statistically on par with T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (2.83) followed by T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (3.16) and statistically on par with T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (3.19), followed by T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.42), followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (4.09). Significantly higher total sedge weed density was recorded with T_7 (unweeded control) (7.90).

At 80 DAT and at harvest significantly lower total sedge weed density was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.92,3.02) which was statistically on par with T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.36,3.62) and T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (3.49,3.63) and were in turn on par with T_4 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (3.66,4.14) which was statistically on par with T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.78,4.14), followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (4.70,4.97).

Significantly total higher sedge weed density was recorded with T_7 (unweeded control) (7.70,7.36). Lower total sedge weed density in different weed management practices might be due to elimination of sedges effectively with herbicide mixtures. These results are in conformity with Devigegan *et al.* (2017) and Yadav *et al*. (2019).

Total broad leaved weed density

Data pertaining to effect of different weed management practices on total broad leaved weed density was recorded at 20 DAT (initial count *i.e.,* before treatment imposition), at 40, 60, 80 DAT and at harvest were recorded after treatment imposition. Data was analysed statistically and presented in Table.4.

At 20 DAT, significantly the lowest broad leaved weed density was registered with T_6 (weed free hand weeding at 20, 40 and 60 DAT) 1.5) (followed by T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (3.3) which was statistically on par with T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (3.4), T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (3.4) and T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.6) followed by T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (4.5). Significantly higher total broad leaved weed density was recorded with T_7 (unweeded control) (4.7).

At 40 DAT, significantly the lowest broad leaved weed density was registered with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.1) it was statistically on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (2.5) and T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (2.5), which was in turn on par with T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (2.7) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (2.8), followed by T_2 (application of penoxsula1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (3.1). Significantly total higher broad leaved weed density was recorded with T_7 (unweeded control) (4.8).

At 60 DAT, significantly the lowest broad leaf weed density was registered with T_6(weed free hand weeding at 20, 40 and 60 DAT) (2.3) it was statistically on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (2.9) and T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (3.0) which were inturn on par with T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.1) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.2), followed by T_2 (application of penoxsulam

1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (3.8). Significantly higher total broad leaved weed density was recorded with T_7 (unweeded control) (5.1).

Table 2 : Total grass weed density of rice as influenced by weed management practices at different crop growth stages during *kharif,* 2022

Treatments	20 DAT	40 DAT	60 DAT	80 DAT	Harvest
T_1: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer.	3.87 (14.00)	2.45 (5.00)	3.08 (8.50)	2.95 (7.70)	2.74 (6.50)
T_2: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone.	3.61 (12.00)	2.88 (7.30)	3.81 (13.50)	3.95 (14.60)	3.69 (12.60)
T_3: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone.	3.94 (14.50)	3.21 (9.30)	3.18 (9.10)	3.19 (9.20)	3.18 (9.10)
T_4: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone.	3.70 (12.70)	2.53 (5.400)	2.98 (7.90)	3.08 (8.50)	3.07 (8.40)
T_5: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone.	3.61 (12.00)	2.41 (4.80)	2.95 (7.70)	2.95 (7.70)	2.77 (6.70)
T_6: Weed free (Hand weeding at 20, 40 and 60 DAT)	2.00 (3.00)	1.97 (2.90)	2.32 (4.40)	2.45 (5.00)	2.30 (4.30)
T_7: Unweeded control	4.91 (23.10)	6.05 (35.60)	7.68 (58.00)	7.36 (53.20)	6.91 (46.80)
SE(m)±	0.13	0.14	0.18	0.27	0.29
CD (P=0.05)	0.41	0.42	0.55	0.82	0.89

* Values in the parenthesis are original and (√x+1) transformed values

Table: 3 Total sedge weed density of rice as influenced by weed management practices at different crop growth stages during *kharif,* 2022

Treatments	20 DAT	40 DAT	60 DAT	80 DAT	Harvest
T_1: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer.	3.61 (12.00)	3.00 (8.00)	2.83 (7.00)	3.36 (10.30)	3.62 (12.10)
T_2: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone.	3.71 (12.80)	3.67 (12.50)	4.09 (15.70)	4.70 (21.10)	4.97 (23.70)
T_3: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone.	3.71 (12.80)	3.35 (10.20)	3.42 (10.70)	3.78 (13.30)	4.14 (16.10)
T_4: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone.	3.63 (12.20)	3.21 (9.30)	3.19 (9.20)	3.66 (12.40)	4.14 (15.90)
T_5: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone.	3.51 (11.30)	3.03 (8.20)	3.16 (9.00)	3.49 (11.20)	3.63 (12.20)
T_6: Weed free (Hand weeding at 20, 40 and 60 DAT)	1.61 (1.60)	2.05 (3.20)	2.47 (5.10)	2.92 (7.50)	3.02 (8.10)
T_7: Unweeded control	5.07 (24.70)	6.27 (38.30)	7.90 (61.40)	7.70 (58.30)	7.36 (53.20)
SE(m)±	0.18	0.17	0.16	0.22	0.21
CD (P=0.05)	0.54	0.54	0.49	0.68	0.64

* Values in the parenthesis are original and (√x+1) transformed values

At 80 DAT, significantly the lowest broad leaved weed density was registered with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.6) and was statistically on par with T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.0) which were in turn on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (3.1), T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (3.1) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.3), followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (4.1). Significantly higher total broad leaved weed density was recorded with T_7 (unweeded control) (4.8).

At harvest significantly the lowest broad leaved weed density was registered with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.9) followed by T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.5) it was statistically on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (3.6) followed by T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (4.0) it was statistically on par with T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (4.1) followed by T_7 (unweeded control) (4.2). Significantly higher total broad leaved weed density was recorded with T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (4.8).

Total weed density

Data pertaining to effect of different weed management practices on total weed density was analyzed statistically found to vary significantly was presented in Table.5.

Significantly lower total weed density at 20 DAT (before treatment imposition) was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.76) followed by T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (5.86) it was statistically on par with rest of the treatments *i.e.,* T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (6.02), T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (6.05), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (6.24) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (6.28). Significantly higher total weed density was recorded with T_7 (unweeded control) (8.13).

At 40, 60 DAT significantly lower total weed density was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (3.46, 3.87), followed by T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (4.38, 4.90) and was statistically on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (4.42, 5.03), T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (4.69, 5.10) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (4.90, 5.48). Followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (5.41, 6.60).

Significantly higher total weed density was recorded with T_7 (unweeded control) (9.35, 10.43). It infers the application of post emergence herbicide either by using knapsack sprayer or by drone significantly reduced the total weed density and both were on par with each other. The lower weed density was noticed with post emergence application of herbicide might be due to effective control of weeds. These results are in tune with Saranraj *et al.* (2018), Kashid (2019), Yogananda *et al.* (2019) and supriya *et al.* (2021). Post emergence application of 2, 4-D @ 1kg a.i ha^{-1} on 30-35 days after sowing (DAS) recorded lower total weed density.

After the treatment imposition at 40, 60 DAT total weed density was lower due to PoE herbicide application either by using knapsack sprayer or drone at recommended doses (T_1 – 18.2, 23.0 and T_3 – 23.0, 29.0 respectively). Application of PoE at higher doses than the recommended doses recorder lower total weed density due to higher weed suppression. High total weed density was noticed in T_2 Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone (25% reduction than the recommended dose). It was clearly evident that reducing the herbicide quantity severally increase the total weed density (28.3, 42.6 respectively at 40, 60 AT) similar finding was reported by Paul *et al.* (2023).

There was no difference between knapsack and drone for the application of PoE. It also confirmed that reduced quantity of carrier volume from 500 lit/ha in knapsack sprayer to 40 lit/ha while using drone did not affected the herbicide efficacy (Chen *et al*., 2019), (Martin *et al*., 2020) and (Paul *et al*., 2023).

Decreased the total weed density of drone at higher dose of PoE than recommended doses due to increase the droplet deposition on abaxial surface of weed foliage which was manifested by their decreased weed dry weight (Paul *et al*., 2023).

At 80 DAT, significantly lower total weed density was recorded with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (4.38) and was statistically on par with T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (5.20) and T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (5.32) further they were inturn on par with T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (5.59) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (5.79). T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (7.25) recorded significantly higher total weed density among the herbicide treated plots. Significantly the highest total weed density was recorded with T_7 (unweeded control) (11.86).

At harvest, significantly lower total weed density was recorded with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (4.60), followed by T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (5.57) and was statistically on par with T_5 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (5.70). Followed by T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (6.60) and was statistically on par with T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (6.67). Followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (7.72). Significantly higher total weed density was recorded with T_7 (unweeded control) (12.19).

The study revealed that at all stages of observation, weedy check recorded the maximum number of weed population indicating the native soil is full of weed seeds. All herbicidal treatments reduced the weed population significantly compared with weedy check. Hand weeding was more efficient to destroy all groups of weeds. The lowest total weed density was recorded in application of herbicides using both drone and knapsack sprayer reflecting its high bio-efficacy in controlling and suppressing weed growth. These results were similar with findings of Sah *et al.* (2012) and Paul *et al.* (2023).

Table 4 : Total broad leaved weed density of rice as influenced by weed management practices at different crop growth stages during *kharif,* 2022

Treatments	20 DAT	40 DAT	60 DAT	80 DAT	Harvest
T_1: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer.	3.6 (11.80)	2.5 (5.20)	3.1 (8.50)	3.0 (8.00)	3.5 (11.40)
T_2: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone.	3.4 (10.80)	3.1 (8.80)	3.8 (13.50)	4.1 (15.90)	4.8 (22.30)
T_3: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone.	4.5 (18.90)	2.8 (6.90)	3.2 (9.10)	3.3 (10.00)	4.1 (16.20)
T_4: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @150 g a.i ha^{-1} using drone.	3.4 (10.70)	2.7 (6.30)	3.0 (7.90)	3.1 (8.50)	4.0 (14.90)
T_5: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone.	3.3 (10.00)	2.5 (5.50)	2.9 (7.70)	3.1 (8.40)	3.6 (12.00)
T_6: Weed free (Hand weeding at 20, 40 and 60 DAT)	1.5 (1.40)	2.1 (3.30)	2.3 (4.40)	2.6 (5.60)	2.9 (7.70)
T_7: Unweeded control	4.7 (21.40)	4.8 (22.50)	5.1 (25.00)	4.8 (22.20)	4.2 (17.00)
SE(m)±	0.15	0.16	0.23	0.14	0.18
CD (P=0.05)	0.48	0.49	0.72	0.44	0.56

* Values in the parenthesis are original and (√x+1) transformed values

Table 5 : Total weed density of rice as influenced by weed management practices at different crop growth stages during *kharif,* 2022

Treatments	20 DAT	40 DAT	60 DAT	80 DAT	Harvest
T_1: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer.	6.24 (38.00)	4.38 (18.20)	4.90 (23.00)	5.20 (26.00)	5.57 (30.00)
T_2: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone.	6.05 (35.60)	5.41 (28.30)	6.60 (42.60)	7.25 (51.60)	7.72 (58.60)
T_3: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone.	6.28 (38.50)	4.90 (23.00)	5.48 (29.00)	5.79 (32.50)	6.67 (43.50)
T_4: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone.	6.02 (35.20)	4.69 (21.00)	5.10 (25.00)	5.59 (30.20)	6.60 (42.50)
T_5: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone.	5.86 (33.30)	4.42 (18.50)	5.03 (24.30)	5.32 (27.30)	5.70 (31.50)
T_6: Weed free (Hand weeding at 20, 40 and 60 DAT)	2.76 (6.60)	3.46 (11.00)	3.87 (14.00)	4.38 (18.20)	4.60 (20.20)
T_7: Unweeded control	8.13 (65.10)	9.35 (86.40)	10.43 (107.70)	11.86 (139.70)	12.19 (147.70)
SE(m)±	0.18	0.21	0.31	0.30	0.28
CD (P=0.05)	0.54	0.63	0.92	0.93	0.85

* Values in the parenthesis are original and (√x+1) transformed values

Total weed dry weight

Weed dry matter is a better parameter to measure weed competition than weed density as it measures more precisely the growth resources utilized by weeds. Results related to total weed dry weight are presented in Table 6. Weed dry matter was significantly influenced by different weed management practices.

Significantly lower total weed dry weight at 20 DAT (before treatment imposition) was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (2.57) followed by T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (4.90) and was statistically on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (4.94), T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (4.99), T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (5.00) and T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (5.03). Significantly higher total weed dry weight was recorded with T_7 (unweeded control) (7.89). It was indicating total weed dry matter (g m^{-2}) was on par in all the treatments that before the post emergence herbicide application.

At 40 DAT, significantly lower total weed dry weight was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (3.01) it was statistically on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (3.36), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.38) which were inturn on par with T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1}using drone) (3.70) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (3.90), it was followed by T_2 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (5.05). Significantly higher total weed dry weight was recorded with T_7 (unweeded control) (9.31). It infers that at 40 DAT, application of post emergence herbicide using knapsack sprayer at recommended dose effectively reduced the weed dry weight and was comparable to herbicides application by using drones.

At 60 DAT, significantly lower total weed dry weight was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (3.97) it was statistically on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (3.95), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl OD @ 120 g a.i ha^{-1} using knapsack sprayer) (3.97), T4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (4.27) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (4.59). It was followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (5.73), Significantly higher total weed dry weight was recorded with T_7 (unweeded control) (11.69).

After the treatment imposition at 40, 60 DAT weed dry weight was lower due to PoE herbicide application either by using knapsack sprayer or drone at recommended doses (T_1 – 10.4, 14.8 and T_3 – 17.4, 20.1 respectively). Application of PoE at higher doses than the recommended doses recorder lower weed dry weight (T_5 – 10.3, 14.6 and T_4 – 17.4, 20.1 respectively), due to higher weed suppression of weeds with PoE application. High weed dry weight was noticed in T_2 Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone (25% reduction than the recommended dose). It was clearly evident that reducing the herbicide quantity severally increase the weed dry weight (24.5, 31.8 respectively at 40,60 DAT).

It was observed that by decreasing the 25% in the recommended dose of post emergence herbicide application using drone (T_2), increased the weed dry weight by 26.6%. Hence it was indicating that quantity of herbicide should not be decreased to achieve desired weed control. Application of post emergence herbicide by using drones with increasing the recommended dose by 25% (T_4) and 50% (T_5), decreased the weed dry weight by 7.6% and 7.1% respectively but was at par with recommended dose (T_3). Weed control up to 60 DAT majorly influenced the rice crop and yield. Similar findings were reported by chinnuswamy *et al.* (2000). At lower dose weeds are less effectively controlled due to the less activity of herbicide on weeds.

There was no difference between knapsack and drone for the application of PoE. It also confirmed that reduced quantity of carrier volume from 500 lit/ha in knapsack sprayer to 40 lit/ha while using drone did not affected the herbicide efficacy (Chen *et al.*, 2019), (Martin *et al.*, 2020) and Paul *et al.*, 2023).

Decreased the weed dry weight of drone at higher dose of PoE than recommended doses due to increase the droplet deposition on abaxial surface of weed foliage which was manifested by their decreased weed dry weight (Paul *et al.*, 2023). While spraying with drone the droplet size is small and effectively distributed on both sides of leaf.

At 80 DAT, Significantly lower weed dry weight was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (4.25) followed by T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (5.05), T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (5.09), T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (5.68) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (5.75) was followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (6.80). Significantly higher total weed dry weight was recorded with T_7 (unweeded control) (12.30). At 80 DAT knapsack sprayer with recommended dose of herbicide effectively reduce the weed dry weight (5.0), compare to drone at recommended dose of herbicide (5.7) but both were on par with each other.

At harvest, Significantly lower weed dry weight was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (4.98) and was statistically on par with T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (5.21), T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (5.23), T_4 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (5.78) and T_3 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (5.71). Followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (6.87). Significantly higher total weed dry weight was recorded with T_7 (unweeded control) (12.33) throughout the crop stage. In unweeded control long weed growth recorded the higher weed dry weight because of the absence of control measures, exploited the native and applied nutrients in greater amount beside enjoying the natural resources like sunlight etc. Resulting in better weed growth for achieving higher dry weight production this again leads to poor growth and yield of the crop. However, in hand weeding plots less weed dry weight production was due to the destruction of weeds through weeding thrice (Reddy *et al.*, 2012). The lowest total weed dry weight recorded in application of herbicides using both drone and knapsack sprayer (Paul *et al.*, 2023). These results are in tune with findings of Kashid (2019), Saranraj *et al.* (2018) and Yogananda *et al.* (2019).

Grain yield

The results showed that grain yield was significantly influenced with various weed management practices (Table 4).

Rice grain yield was significantly higher with T_6 (weed free hand weeding at 20, 40 and 60 DAT) (6207) and was statistically on par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) (6239), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) (6207), T_4 (application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) (6186) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) (6029) followed by significantly lower grain yield recorded in T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (4653). Significantly the lowest grain yield was registered with T_7 (unweeded control) (2570).

It was observed that by decreasing the 25% in the recommended dose of post emergence herbicide application using drone (T_2), decreased the rice grain yield by 22.82%. Hence it was indicating that quantity of herbicide should not be decreased to achieve desired grain yield. Application of post emergence herbicide by using drones with increasing the recommended dose by 25% (T_4) and 50% (T_5), Increased the rice grain yield by 2.53% and 3.36% respectively but was on par with recommended dose (T_3). It was clearly evident that reducing the herbicide quantity severally effected the grain yield (4653 kg ha^{-1}) (T_2). Paul *et al.* (2023).

Efficient utilization of light, water and nutrients resources by crop in presence of relatively low weed density and dry weight led to maximum grain yield was (6318 kg ha^{-1}) with hand weeding at 20, 40 and 60 DAT. Weed management practices not only reduced weed density and dry matter also allowed the plant to use available resources efficiently which resulted in higher growth parameters and yield attributes ultimately led to higher yield over unweeded control. Similar reports were by Chowdhary and Dixit (2018), (Kashid 2019), (Singh *et al.* 2019) and Ramesha *et al.* (2019).

The lowest rice yield was recorded in unweeded control, which was due to high weed density and biomass that adversely affected all the yield parameters. Similar results were reported by Atheena *et al.* (2017) and Venkatesh *et al.* (2021).

Table 6 : Grain yield of rice as influenced by different weed management practices during *kharif,* 2022

Treatments	Grain yield (kg ha^{-1})
T_1: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer.	6207
T_2: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone.	4653
T_3: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone.	6029
T_4: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone.	6186
T_5: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone.	6239
T_6: Weed free (Hand weeding at 20, 40 and 60 DAT)	6318
T_7: Unweeded control	2570
SE(m)±	142.4
CD (P=0.05)	438

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