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Impact of drone-based post-emergence herbicide application on nutrient depletion by weeds and grain yield of transplanted rice (*Oryza sativa* L.)

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Abstract

Field experiment was carried out during *Kharif*, (2022) in Rice Research Centre, Agriculture Research Institute, Rajendranagar, Hyderabad to evaluate the post-emergence herbicide efficacy for drone spraying in transplanted rice (*Oryza sativa* L.). The experiment was designed in RBD with 7 treatments and was replicated thrice. Results indicated that among all the treatments, significantly higher nutrient removal by weeds at all stages was observed in unweeded control. Hand weeding at 20, 40 and 60 DAT recorded lower nutrient removal by weeds and higher grain yield followed by penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha⁻¹ application with drone and it was statistically on par with application 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.

Keywords: Cyhalofop-butyl, drone, herbicide efficacy, penoxsulam, transplanted rice

Introduction

Rice (*Oryza sativa* L.) is the most widely cultivated and consumed grain globally, serving as the staple food for billions of people. In India, rice plays a crucial role in the economy, providing direct employment to approximately 70% of the rural population (Saha *et al.*, 2017) ^[10]. As the world's most populous country, China leads in rice consumption, with approximately 155 million metric tons consumed in 2022/2023. India follows closely, ranking second with a consumption of 108.5 million metric tons during the same period (Rice consumption worldwide in 2022/2023, by country, in 1,000 metric tons). In terms of production, China remained the top producer in the 2021/2022 crop year, yielding over 148 million metric tons of milled rice, while India ranked second with over 129 million metric tons. The total global production of milled rice was estimated to surpass 502 million metric tons in the 2022/2023 crop year (www.statista.com, 2022-2023).

Rice cultivation faces numerous biotic and abiotic challenges, with weeds being one of the most significant yield-limiting biotic factors. Weeds compete with rice plants for essential resources such as nutrients, moisture, and sunlight. Kumar *et al.* (2010) ^[7] reported that in uncontrolled weedy plots, rice grain yield was reduced by 70.4% in 2006 and 67.4% in 2007 compared to plots where weed control measures were applied. Among weed species, grassy weeds posed the highest competition, followed by sedges and broadleaf weeds.

A drone, or Unmanned Aerial Vehicle (UAV), is essentially a flying robot that is remotely controlled through software-guided flight plans integrated into its embedded system, working in coordination with sensors and Global Positioning System (GPS). The high adaptability of UAV platforms makes them a viable alternative for aerial pesticide application (Wang *et al.*, 2018) ^[13]. Originally designed for military use, UAVs have evolved with advancements in technologies such as sensors, GPS, and civilian-accessible computing, expanding their applications beyond defence (Ehsani & Maja, 2013; Hogan *et al.*, 2017) ^[3, 5]. Due to their flexibility, drones offer an efficient solution for aerial chemical spraying (Wang *et al.*, 2018) ^[13]. They also assist farmers by saving time and supporting various agricultural tasks, including soil fertilization, spraying,

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irrigation, crop health monitoring, planting and herd tracking. Additionally, drones can operate in challenging environments such as damp or sloping terrains, reduce labour intensity and enable targeted applications in specific locations.

Materials and Methods

A field study was carried out during the *Kharif* season of 2022 at the Rice Research Centre, Agricultural Research Institute, Rajendranagar, Hyderabad. The experimental site featured clay loam soil with a neutral pH of 7.6, an electrical conductivity (EC) of 0.71 dS m⁻¹ and organic carbon content of 0.45%. The available nutrient levels were 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 (RBD) with seven treatments, each replicated three times. The rice variety RNR-15048 was sown at a seed rate of 50 kg ha⁻¹, maintaining a

spacing of 15 cm × 15 cm keeping two seedlings per hill. The nutrient management for transplanted rice included 120:60:40 kg ha⁻¹ of N, P₂O₅ and K₂O. Nitrogen was delivered in three equal splits at transplanting, the maximum tillering stage and the panicle initiation stage, while complete phosphorus dose was administered as a basal dose. Two equal splits of potassium were applied, one during transplanting and the other after panicle initiation. Herbicide application was performed at different growth stages: Pre-emergence (PE) herbicide was applied 3 days after transplanting (DAT). Post-emergence (PoE) herbicide was applied 30 DAT using 500 liters of water per hectare as a spray fluid with a flat-fan nozzle-fitted knapsack sprayer and 40 liters of water per hectare when applied via drone. Observations were recorded on plant height (cm), number of tillers (m⁻²), number of panicles (m⁻²), grain yield (kg ha⁻²) at harvest and weed dry matter at 60 DAT.

Table 1: Treatment description

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

Results and Discussion

Nutrient removal by weeds (N, P and K) (kg ha⁻¹)

Nutrient removal is function of nutrient concentration and their biomass. Impact of various weed management techniques on the removal of nutrients (N, P and K) by weeds at 20, 40, 60 DAT and harvest are presented in Table 2 to 4. Unweeded control recorded significantly higher nutrient removal by weeds at all stages. At 20 DAT, lower nutrient removal was observed with T₆ - weed free hand weeding at 20, 40 and 60 DAT followed by T₅ - application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha⁻¹ using drone it was statistically on par with T₁ - application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha⁻¹ using knapsack sprayer, T₄ - application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha⁻¹ using drone, T₃ - application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha⁻¹ using drone and T₂ - application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha⁻¹

using drone. At 40, 60, DAT and at harvest lowest nutrient removal was observed with T₆ - weed free hand weeding at 20, 40 and 60 DAT and it was statistically on par with T₅ - application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha⁻¹ using drone, T₁ - application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha⁻¹ using knapsack sprayer, T₄ - application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha⁻¹ using drone and T₃ - application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha⁻¹ using drone followed by T₂ - application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha⁻¹ using drone. Higher nutrient removal was observed with treatment T₇ -unweeded control. Reduced nutrient removal by weeds attributed to successfully suppression of weeds during crucial phases of crop. Similar findings were observed by Gupta and Tomar (2019) [4].

Table 2: Impact of different weed management practices on nitrogen removal (kg ha⁻¹) by weeds in transplanted rice

Treatments	20 DAT	40 DAT	60 DAT	Harvest
T ₁ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha ⁻¹ using knapsack sprayer.	2.40	0.84	1.45	3.30
T ₂ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha ⁻¹ using drone.	2.50	1.86	2.88	5.69
T ₃ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha ⁻¹ using drone.	2.41	1.10	1.82	4.16
T ₄ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha ⁻¹ using drone.	2.40	1.12	1.60	4.31
T ₅ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha ⁻¹ using drone.	2.41	0.81	1.47	3.48
T ₆ : Weed free (Hand weeding at 20, 40 and 60 DAT)	0.67	0.73	1.35	3.21
T ₇ : Unweeded control	6.58	8.89	9.96	16.38
SE(m)±	0.1	0.15	0.46	0.43
CD (P=0.05)	0.29	0.48	1.36	1.28

Table 3: Impact of different weed management practices on phosphorus removal (kg ha⁻¹) by weeds in transplanted rice

Treatments	20 DAT	40 DAT	60 DAT	Harvest
T ₁ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha ⁻¹ using knapsack sprayer.	0.60	0.30	0.41	0.82
T ₂ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha ⁻¹ using drone.	0.51	0.69	0.87	1.21
T ₃ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha ⁻¹ using drone.	0.61	0.32	0.50	0.90
T ₄ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha ⁻¹ using drone.	0.62	0.30	0.52	1.00
T ₅ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha ⁻¹ using drone.	0.50	0.31	0.51	0.81
T ₆ : Weed free (Hand weeding at 20, 40 and 60 DAT)	0.30	0.20	0.40	0.81
T ₇ : Unweeded control	1.01	1.52	3.46	3.95
SE(m)±	0.04	0.06	0.07	0.09
CD (P=0.05)	0.12	0.18	0.21	0.28

Table 4: Impact of different weed management practices on potassium removal (kg ha⁻¹) by weeds in transplanted rice

Treatments	20 DAT	40 DAT	60 DAT	Harvest
T ₁ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha ⁻¹ using knapsack sprayer.	2.49	1.00	1.20	3.80
T ₂ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha ⁻¹ using drone.	2.51	2.45	2.69	6.88
T ₃ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha ⁻¹ using drone.	2.43	1.42	1.61	4.72
T ₄ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha ⁻¹ using drone.	2.56	1.45	1.40	4.70
T ₅ : Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha ⁻¹ using drone.	2.50	0.98	1.13	3.83
T ₆ : Weed free (Hand weeding at 20, 40 and 60 DAT)	0.59	0.73	1.08	3.41
T ₇ : Unweeded control	4.47	5.24	7.69	15.46
SE(m)±	0.13	0.24	0.35	0.44
CD (P=0.05)	0.39	0.71	1.05	1.31

Grain yield (kg ha⁻¹)

Different weed management practices significantly impacted the grain yield of transplanted rice (Table 5). Rice grain yield was significantly higher with T₆ (weed free hand weeding at 20, 40 and 60 DAT) and was statistically comparable with T₅ (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha⁻¹ using drone), T₁ (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha⁻¹ using knapsack sprayer), T₄ (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha⁻¹ using drone) and T₃ (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha⁻¹ using drone). Significantly the lowest grain yield was registered with T₇ (unweeded control).

The rice grain yield was found to drop by 22.82% by application of 25% reduced dose from the recommended dose of post emergence herbicide (T₂). Therefore, it was evident that in order to attain the intended grain yield, the amount of herbicide should not be reduced. Instead, the rice grain yield improved by 2.53% and 3.36%, respectively, when post-emergence herbicide was applied with increased the recommended dose by 25% (T₄) and

50% (T₅), but it was still comparable to the recommended dose (T₃). It was clearly evident that reducing the herbicide quantity severely effected the grain yield (4653 kg ha⁻¹) (T₂). These results were in line with Paul *et al.* (2023) [8].

The maximum grain yield was 6318 kg ha⁻¹ with hand weeding at 20, 40, and 60 DAT due to the crop's efficient use of light, water, and nutrient resources in the presence of relatively low weed density and dry weight. In addition to lowering weed density and dry matter, weed management techniques made it possible for the plant to make effective use of the resources at its disposal, which raised growth parameters and yield attributes and eventually increased yield compared to unweeded control. The studies by Chowdhary and Dixit (2018), Kashid (2019) [6], Singh *et al.* (2019) [11] and Ramesha *et al.* (2019) [9] corroborated the present findings.

Unweeded control had lowest rice yield due to high weed density and dryweight that adversely affected all the yield parameters. Similar results were reported by Atheena *et al.* (2017) [2] and Venkatesh *et al.* (2019) [12].

Table 5: Impact of different weed management practices on grain yield of transplanted rice

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

Conclusion

The study demonstrated that maintaining a weed-free condition through manual weeding produced the highest yield and lowest nutrient removal. However, the application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD using drone showed comparable results, demonstrating its effectiveness as an alternative to conventional methods. The findings also indicate that reducing herbicide dosage below recommended levels negatively affects yield, while increasing the dose offers no substantial advantage.

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