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Influence of post emergence herbicide through drone spraying using different nozzles on the growth and yield of transplanted rice (*Oryza sativa* L.)

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Abstract
A field experiment was conducted at Military Farm Agriculture Research Institute (ARI) Main farm, Rajendranagar, Hyderabad during *Kharif*, 2023. The experiment was laid out in randomized block design with eight treatments and replicated thrice. Results revealed that among the herbicidal treatments, post emergence herbicide application of triafamone 20%+ ethoxysulfron 10% WG @44+22.5 g ha^{-1} PoE using knapsack sprayer with nozzle (flat fan nozzle) has recorded the higher plant height (cm), number of tillers m^{-2}, plant dry matter accumulated (kg ha^{-1}) at harvest and grain yield (kg ha^{-1}). It was statistically on par with the application of triafamone 20%+ ethoxysulfron 10%WG 44+22.5 g ha^{-1} PoE using drones with multiple solid stream (SJ7A015VP) nozzle, triafamone 20%+ ethoxysulfron 10%WG 44+22.5 g ha^{-1} PoE using drones with air induction extended range flat spray (AIXR110015VS) nozzle and triafamone 20%+ ethoxysulfron 10%WG 44+22.5 g ha^{-1} PoE using drones with drift guard even flat spray (DG95015EVS) nozzle.

Keywords: Drone, rice, nozzle, post emergence herbicide, triafamone, ethoxysulfuron, weed and drift

Introduction
Rice (*Oryza sativa* L.) is a seed staple food for more than 60% of the world's population and plays a crucial role in the economic and social stability of the world. However, the productivity of rice in India is very low compared to other rice growing countries like China (4.3 t ha^{-1}), Australia (10.1 t ha^{-1}), U.S (7.5 t ha^{-1}) and Russia (5.2 t ha^{-1}) (Yadav *et al.*, 2019) [1]. It is estimated that 40% of more rice production will be required by 2030 to satisfy growing demand with no increases in cropping areas (Khush, 2005) [2]. Weeds are one of the most important yield-limiting biological constraints in rice production worldwide. The estimated annual losses due to weeds in India account to 4420 million USD (Gharde *et al*. 2018) [3]. Weeds not only cause quantitative losses, but also hamper the quality of produce due to competition for nutrients, moisture, light and space.
The diverse weed flora under transplanted conditions (grasses, sedges and broad-leaved weeds) can cause yield reduction up to 76% (Singh *et al*., 2004) [4]. Globally, about 10% of the total production of rice is lost due to weed infestation (Oerke and Dehne, 2004) [5]. Weeds are the universal pests in rice that exceed tolerable levels in all seasons. Therefore, it is necessary to invest in weed management practices to reduce yield losses caused by weed competition.
About 300–400 man hours per hectare are required to remove weeds from transplanted rice field. Thus, due to increasing labour shortage problem herbicide-based weed management system is becoming the most popular method of weed control in rice (Mahajan and Chouhan, 2008) [6]
Conventionally farmers spray herbicide by hand operated sprayer with a high volume of spray fluid. It consumes more time and involves drudgery due to walking in the puddled field with tank load and spraying, which is hindering the weed control efficiency. Agricultural labour are considerably shifting towards non-agricultural sector (Srivastava *et al*. 2020) [7] and agricultural labour workforce is reduced by 30.7 million labours (12% reduction) which cause hike in labour

wages by 9.3% (Vaishnavi and Manisankar, 2022) [8]. To address these challenges, advanced technology is inevitable in agriculture in order to save time and energy. Drone being a modern technology can be one of the solutions for farmers.

"A Drone (Unmanned Aerial Vehicle) is essentially flying ROBOT remotely controlled through software-controlled flight plans in their embedded system working in conjunction with on-board SENSORS and GPS (Global Positioning System) (Wang *et al*., 2018) [9]. Agricultural use of unmanned aerial vehicles (UAVs) for herbicide application offers a new high-tech tool for weed management. Electric multi-rotor UAV sprayers featured with autonomous flight control to deliver herbicides to an array of crops is now a common substitute for traditional knapsack application. The UAV technology helps to mitigate intensifying labour pressure caused by an aging farm population.

The nozzle is the only component in spraying system that directly determines the efficacy of the herbicide and effectiveness of spraying. In UAV based herbicide spraying for the uniform distribution of spray fluid on the target plant and minimization of drift losses the selection of appropriate nozzle plays a crucial role. As the nozzle breaks the spray liquid into droplets to form a spray pattern and simultaneously propel the droplets in proper direction. The deposition distribution and penetration of droplets in the target area and the drift distribution of droplets in the non-target area were influenced by the droplet size which is directly related with the volume median diameter of the nozzle (Chen *et al*., 2020) [10]. The presence of a wind field generated by the rotors of plant protection UAV, the influence of droplet size on droplet deposition and drift would be more significant and droplet size needs to be regarded as the most important factor for the research of aerial spraying technology.

Thus, study on spray drift of the UAV sprayer has been a new hot spot within the field of pesticide application technology. Very little research has been conducted to optimize application parameters and measure the potential of off-target movement from UAV-based pesticide applications and Coverage percent consistently decreases as application speed increased (Hunter *et al*., 2020) [11].

Therefore, using an appropriate nozzle for the spray of herbicide application is most important in drone-based herbicide spraying. This study helps in understanding the type of nozzle to be selected for spray fluid application to increase the efficiency of weed management by selection of proper nozzle by using drone vs-a-vis knapsack sprayer.

Materials and Methods

A field experiment was conducted at Military Farm Agriculture Research Institute (ARI) Main farm, Rajendranagar, Hyderabad during *Kharif*, 2023. The soil type was clay loam soils and neutral in nature (pH 7.46), having an EC of 0.65 dS m^{-1}, organic carbon (0.45 %), available nitrogen (218.5 kg ha^{-1}), phosphorous (36.8 kg ha^{-1}), and potassium (439.7 kg ha^{-1}). The experiment was laid out in randomized block design with 8 treatments and replicated thrice. The variety sown was RNR-15048 and the seed rate used was 50 kg ha^{-1}, with a spacing of 15 × 15 cm with two seedlings per hill. The fertilizers applied in the form of urea, di ammonium phosphate and murate of potash at a dose of 120:60:40 N, P_2O_5, K_2O kg ha^{-1} respectively. Entire dose of phosphorous was applied as basal whereas, nitrogen was applied in three splits as di ammonium phosphates supply the required nitrogen by substuting that remaining nitrogen was supplied through urea. The remaining two splits of nitrogen was applied at the time of maximum tillering stage and at panicle initiation stage. The recommended dose of potash was applied in two equal splits at the time of transplanting and panicle initiation stage. Pre-emergence (PE) herbicide application was done with pretilachlor 6 % GR bensulfuron methyl 0.6% 10 kg ha^{-1} at 3 days after transplanting (DAT) and PoE herbicide application at 26 DAT using 500 liters of water ha^{-1} as spray fluid with flat fan nozzle in knapsack sprayer and 40 liters water ha-1 using drone. The observations on plant height (cm), number of tillers (m^{-2}) and plant dry matter (kg ha^{-1}) at harvest were recorded.

Results and Discussion

Plant height at harvest (cm) at harvest

At harvest, significantly higher plant height was recorded in T_7 - hand weeding at 20 and 40 DAT (118.9) and it was statistically at par with T_6 -triafamone 20%+ ethoxysulfron 10%WG @ 44+22.5g ha^{-1} PoE using knapsack sprayer with nozzle (flat fan nozzle) (117.6), T_5 - using drones with multiple solid stream (SJ7A015VP) nozzle (116.1), T_2 - using drones with air induction extended range flat spray (AIXR110015VS) nozzle (115.6) and T_4 - using drones with drift guard even flat spray (DG95015EVS) nozzle (115.1). On the other hand, lowest plant height was recorded in T_8 - Unweeded check (103.2). All the weed management practices recorded significantly higher plant height over unweeded control. Increased plant height in weed management practices compared to unweeded control treatment is due to reduced competition between the crop plant and weeds for the light, nutrients and water etc., The increased plant height in PoE sprayed treatments either by drone spraying using different nozzles or by knapsack sprayer was due to better weed control coupled together with favourable soil environment which might have resulted in reduced crop weed competition for the growth factors such as light, space, nutrients and moisture which supported prolonged photosynthetic activity for assimilation of the nutrients resulting in increased plant height Paul *et al.* (2023) [12].

Number of tillers (m^{-2}) at harvest

At harvest, significantly higher number of tillers were recorded in T_7 - hand weeding at 20 and 40 DAT (392) and it was statistically at par with T_6 - using knapsack sprayer with nozzle (flat fan nozzle) (387), T_5 - using drones with multiple solid stream (SJ7A015VP) nozzle (381), T_2 - using drones with air induction extended range flat spray (AIXR110015VS) nozzle (373) and T_4 -using drones with drift guard even flat spray (DG95015EVS) nozzle (365). On the other side, the lower number of tillers were recorded in T_8 - Unweeded check (215). Because the weeds are competent with the crop for the resources like water, nutrients *etc.*, this might be due to Production and survival of the tillers is dependent on the prevailing environment, which includes the moisture, radiation, temperature and photoperiod which in turn, effect the potential site for tillering. Higher tiller number contributes to early ground cover in the season and this trait helps in competing against the weeds and favours conductive conditions for the crop growth, these results are in line with the findings of Hossain and Malik. (2017) [13], (Suryakala *et al.*, 2019) [14] and Naveen *et al.* (2023) [15].

Plant dry matter accumulation (kg ha^{-1}) at harvest

At harvest, higher dry matter production was recorded in T_7 - hand weeding at 20 and 40 DAT (15368) and it was statistically at par with T_6 - using knapsack sprayer with nozzle (flat fan nozzle) (15053), T_5 - using drones with multiple solid stream (SJ7A015VP) nozzle (14975), T_2 - using drones with air induction extended range flat spray (AIXR110015VS) nozzle (14656) and T_4 - using drones with drift guard even flat spray (DG95015EVS) nozzle (14376).On the other hand, significantly lower number of tillers were recorded in T_8 - Unweeded check (7458), lower dry matter was recorded in all the growth stages due to higher weed competition. Effective control of weeds reduced crop-weed competition and higher availability of the resources to the crop resulted in higher dry matter production in PoE sprayed plots either by drone-based spraying or knapsack sprayer Paul *et al.* (2023). Resource availability to the crop by minimizing the weeds can influence dry weight production of the crop (Meesaragandla *et al.*, 2024) [16].

Grain yield (kg ha^{-1})

Grain is the ultimate product of growth and development which is controlled by growth and yield attributing characters. Significant increase in the grain yield was recorded with different weed management practices. Grain yield of rice was significantly higher with T_7 - hand Weeding at 20 and 40 DAT (6834) and it was statistically at par with T_6 - using knapsack sprayer with nozzle (flat fan nozzle) (6597), T_5 - using drones with multiple solid stream (SJ7A015VP) nozzle (6564), T_2 - using drones with air induction extended range flat spray (AIXR110015VS) nozzle (6190) and T_4 - using drones with drift guard even flat spray (DG95015EVS) nozzle (6137). On the other side, significantly lower grain yield was noticed in T_8 - Unweeded check (2955). Among the drone-based treatments it was observed that by using drones with multiple solid stream (SJ7A015VP) nozzle has recorded the higher yield this was due to production of coarser droplets having higher volume median diameter, due to that there was reduced drift losses due to this nozzle which led to higher bioefficacy in the treated plot and reduced the weed density and weed dry matter Meesaragandla *et al.* (2024) [16].

There was no difference between knapsack sprayer and drone sprayer for the application of PoE herbicide spray. It was reported that application of reduced quantity of carrier volume from 500 L ha^{-1} in knapsack sprayer to 40 L ha^{-1} while using drone did not affected the herbicide efficacy, similar, results are reported in the findings of (Chen *et al*., 2020) [10] and Paul *et al.* (2023) [12].

Table 1: Influence of diverse cropping systems on the yield and economic outcomes of the *Kharif* season, 2023-24.

Treatments	Plant height (cm)	No. of tillers m^{-2}	Plant dry matter (kg ha^{-1})	Grain yield (kg ha^{-1})
T_1: Triafamone 20% + ethoxysulfron 10%WG 44+22.5g ha^{-1} PoE using drones with extended range flat spray (XR11002VP) nozzle.	113.1	337	13542	5763
T_2: Triafamone 20% + ethoxysulfron 10%WG 44+22.5g ha^{-1} PoE using drones with air induction extended range flat spray (AIXR110015VS) nozzle.	115.6	373	14656	6190
T_3: Triafamone 20% + ethoxysulfron 10%WG 44+22.5g ha^{-1} PoE using drones with drift guard flat spray (DG 110015VS) nozzle.	113.5	341	13925	5850
T_4: Triafamone 20% + ethoxysulfron 10%WG 44+22.5g ha^{-1} PoE using drones with drift guard even flat spray (DG95015EVS) nozzle.	115.1	365	14376	6137
T_5: Triafamone 20% + ethoxysulfron 10%WG 44+22.5g ha^{-1} PoE using drones with multiple solid stream (SJ7A015VP) nozzle.	116.1	381	14975	6564
T_6: Triafamone 20% + ethoxysulfron 10%WG @ 44+22.5g ha^{-1} PoE using knapsack sprayer with nozzle (flat fan nozzle).	117.6	387	15053	6597
T_7: Hand Weeding (20 and 40 DAT).	118.9	392	15368	6834
T_8: Unweeded check.	103.2	215	7458	2955
SE(m) ±	1.5	11	409	230
CD (P=0.05)	4.6	34	1242	699

Conclusion

Based on the results, of the present study it can be concluded that in transplanted rice herbicide application of triafamone 20%+ ethoxysulfron 10%WG @ 44+22.5 g ha^{-1} PoE in drone spraying with multiple solid stream (SJ7A015VP) nozzle, air induction extended range flat spray (AIXR110015VS) nozzle and drift guard even flat spray (DG95015EVS) nozzle was proven equally effective with knapsack sprayer with flat fan nozzles when same herbicide was used. Selection of appropriate nozzle for drone based PoE herbicide application is an important parameter as the nozzle influences the droplet size and spray pattern. Among the different nozzles used in the drone based spraying solid stream nozzle produces very coarser droplets and air induction nozzle produces coarse droplets due to production of droplets of higher volume median diameter there is lower losses due to drift and higher amount of spray fluid reaching the desired area which results in higher bio-efficacy and lowering the weed density.

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