



RESEARCH ARTICLE

Efficacy of drone-based pre-emergence herbicide application in wet direct seeded rice

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Received: 10 December 2025; Accepted: 15 April 2026; Available online: Version 1.0: 24 July 2026

Cite this article: Spandana PB, Raghu PRR, Varma NRG, Babu TK. Efficacy of drone-based pre-emergence herbicide application in wet direct seeded rice. Plant Science Today. 2026; 13(sp5): 1-6. <https://doi.org/10.14719/pst.13139>

Abstract

The study was carried out during the rabi season 2021–22 and kharif 2022 at Professor Jayashankar Telangana state Agricultural University, Hyderabad, Telangana, India. The primary objective was to evaluate the comparative efficacy of various sprayers in controlling weeds in wet direct seeded rice (WDSR) and their influence on yield. The randomized block design (RBD) included 7 treatments of pre-emergence (PE) herbicides applied by knapsack and drone sprayers. The grain yield and weed control efficiency (WCE) with knap sack sprayed treatments was found on par with drone with 1.0 X dose hence drones can be deployed for spraying of PE herbicide. Pre-emergence herbicide dose (0.5 x and 0.75 X) significantly decreasing the WCE and yield.

Keywords: drone; pre-emergence herbicide; wet direct seeded rice

Introduction

Weeds are prime most biotic stressors causing yield loss upto 58.85 % while insects cause loss to an extent of 26 % and diseases at 20 % (1). ICAR reported that loss due to weeds account for 33 %. Asian countries accounting for 90 % of global rice production. In India it was cultivated on 435 lakhs ha, producing more than 150 million tons in 2024. Rice is the principal staple food of Telangana population. The present system of rice cultivation in traditional way (nursery raising, puddling, manual transplanting) causing irreversible damage to the environment and contributing factor for climate change. The productivity and sustainability of traditional rice cultivation is doomed because of inefficient use of inputs (labour, water, fertiliser). Increasing scarcity of resources, especially water and labour, changing climate the emerging energy crisis and rising fuel prices, the rising cost of cultivation, emerging socio-economic changes such as urbanisation, migration of labour, preference of non-agricultural work, destroying soil physical conditions, thus limiting the scope for raising non-upland rice crops in rotation. To sustain rice ecosystem there is need of paradigm shift from puddled transplanting to wet direct seeding of rice (WDSR).

The major problem in the direct seeding rice is weed menace. Therefore, effective weed management play role in deciding yield (2).

Traditional methods of weed control, especially manual herbicide spraying, consume more labour, time and spraying is not uniform (3, 4). Additionally, the exposure to the chemicals while spraying is one the risk to the workforce (5). These challenges can be addressed by drone technology which help in uniform application in less time and cost and with more efficiency in weed management

and environmentally friendly (6–8). Weed management in WDSR is the one of the most important yields deciding factor, but efficacy of pre-emergence (PE) herbicides using drones on the weed control efficiency (WCE) is meagre. In WDSR spraying of PE is also a challenging as the walking in sown puddled field may damage the seed/seedlings and weeds which emerge at the same time give a greater competition to the crop, hence the present study was conducted by inspecting the parameters like weed density, weed dry weight and crop parameters and yield.

Materials and Methods

Study area

The experiment was conducted at the Agricultural Research Station, Kampasagar, Nalgonda, India during November 2021 to November 2022. In the experimental study the variety used was Kunaram Sannalu (KNM 118) which was sown using WDSR using drum seeder on 21 December 2021 and 19 August 2022. The fertiliser schedule followed was 150-60-40 kg nitrogen (N), phosphorous (P), potassium (K) (NPK)/ha. Full dose of P and half dose of K supplied fertilisers are applied at the time of sowing. Nitrogen is applied in 3 splits, 1st split applied at 15 days after sowing, 2nd split at maximum tillering stage and final split at panicle initiation stage along with half dose of potash fertiliser. After final land puddling, at sowing the time of sowing all the water removed and a thin film of water was given with intermittent drying till the emergence of seedlings, followed by 2 cm water level maintained till maximum tillering stage and after that 5 cm water level maintained in reproductive stage till attainment of physiological stage.

Experiment was laid out under randomized block design (RBD) with 7 treatments of pre-emergence (PE) herbicide application in 3 replications i.e., T1: pyrazosulfuron ethyl (PSE) 10 % wettable powder (WP) at 100g/ha (0.5x) with drone at 2.75g/L of water, T2: PSE 10 % WP at 150 g/ha (0.75x) with drone at 4.13g/L of water, T3: PSE 10 % WP at 200g/ha (1.0x) with drone at 5.5g/L of water, T4: PSE 10 % WP at 250 g/ha (1.25x) with drone at 6.80 g/L of water, T5: PSE 10 % WP at 300 g/ha (1.5x) with drone at 8.27g/L of water, T6: PSE 10 % WP at 200 g/ha (1.0x) with knapsack at 0.4 g/L of water, T7: untreated control (weedy check). The variety of rice used for the herbicide used for PE application was PSE 10 % WP. Date of PE application: 23 December 2021 and date of post-emergence (PoE) application: 8 January 2022 during rabi and during kharif date of PE: 23 August 2022, date of PoE application: 8 September 2022 respectively.

A minimum 500 m² per treatment will be maintained. A minimum of 50 m length plots were selected to get sufficient and valid observation zone (10 × 10 m) and 5.0 m buffer zone was maintained to avoid drift, contamination and overlaps in drone flying path. At least 3–4 drone pass/loops were allocated to each treatment. The treatment was randomised as per RBD design in the field (Fig. 1).

Herbicide application

Herbicide application done by two different sprayers i.e. i) Knapsack sprayer and ii) Drone

Knapsack sprayer

Pre-emergence herbicide for T₆ PE herbicide applied by knapsack sprayer.

Drone sprayer

The PE (T₁ to T₅) herbicide application was done by (Quadcopter type) drone sprayer having tank capacity 10 L. For drone sprayer, it was tested for different doses PE herbicide.

Phytotoxicity observations like yellowing, stunting, necrosis, leaf injury, vein clearing and wilting. Hyponasty and epinasty were recorded using 0–10 phytotoxicity rating scale at 3, 5, 10 and 15 days after herbicide application (DAHA).

Pre-emergence herbicide application was done 3 days after sowing (DAS) as per the respective treatments. water required for PE application by knapsack sprayer was 500 L ha⁻¹, water required for PE application by drone sprayer was 40 L ha⁻¹. Drone model was AGRICOPTER AG 365 with drone optimum flight height 1.5 m, nozzle type used was XR 11002VP (VMD of extended range - flat fan) with application pressure of 2.8 bar and having orifice size of 2 (0.2 GPM/40 PSI) with 4 number of nozzles with flight speed: 3.6 m/s, spray swath width: 4 m and discharge rate and rotor induced down wash of 60 %.

Statistical analysis

Data on different characters viz., growth, yield attributes and yield, were subjected to analysis of variance (ANOVA) procedures as outlined for RBD (9). Statistical significance was tested by F-value at 0.05 level of probability and critical difference was worked out wherever the effects were significant. In case of observation on weeds, normality of distribution was not seen and hence, the values were subjected to square root transformation ($\sqrt{x + 1}$) prior to statistical analysis to normalise their distribution.

Performance parameters

Weed count (m⁻²)

The number of weeds per square metre was recorded by using one square metre quadrant. This frame was kept in net plot and number of weeds observed inside the frame was recorded at 12 and 24 days after herbicide application.

Dry weed weight

At 12 and 24 days after herbicide application, weeds were uprooted from each plot by using one square metre quadrant and weeds were firstly shade dried and after oven drying at 62 ± 2 °C dry weed weight was recorded in gram per square metre.

Weed control efficiency

It denotes the efficiency of the applied herbicides or herbicidal treatments for comparison purpose. It was worked out by using the formula as below and expressed in percentage.

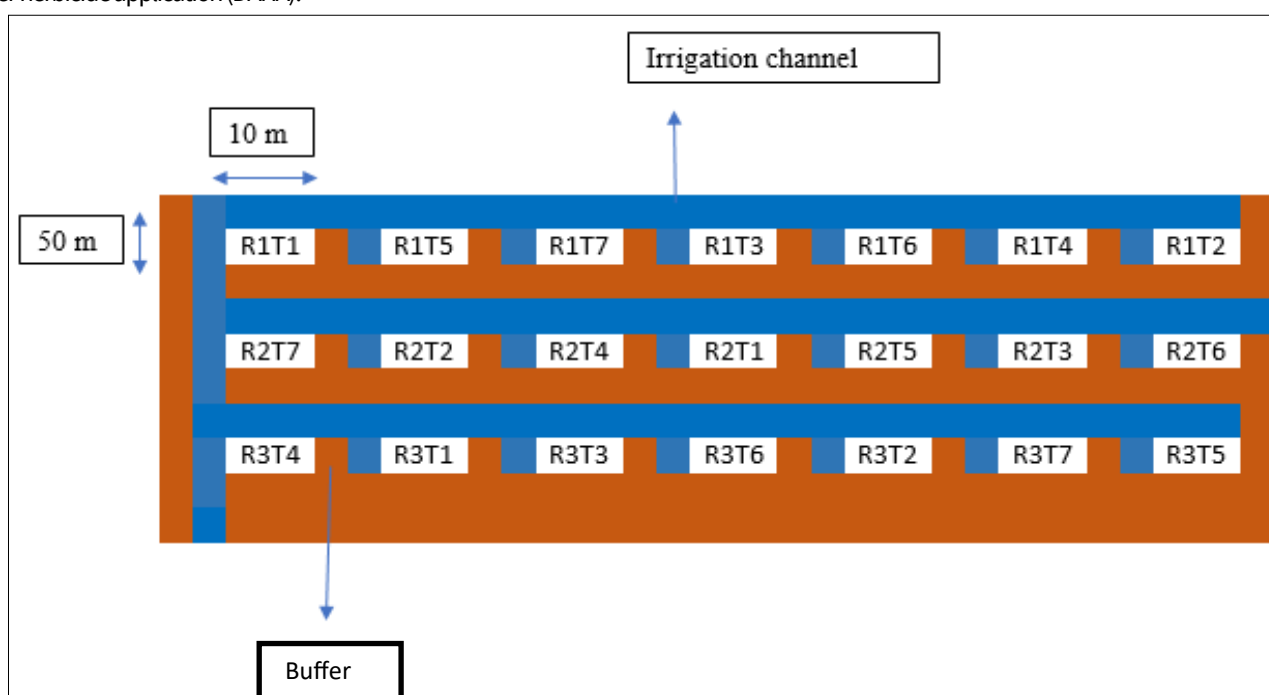


Fig. 1. Layout of the experiment.

$$WCE = \frac{DN_c - DN_T}{DN_c} \times 100$$

Where, DN_c : weed density in unweeded check

DN_T : weed density in treated plot

Results and Discussion

The studies on the impact of PE herbicide PSE 10 % WP at different doses on weed density in WDSR during 2021 and 2022 revealed that at 12 days after herbicide application, the weed density among the treatments ranged from 16.7 to 34.7/m² which were on par with each other but significantly lower compared to untreated control 181.0/m² (Table 1). Whereas the treatment differences were evident during 2022 with weed density varying from 14.3 to 47.0/m² across the treatments and significantly lowest weed density (14.3/m²) was noticed in PSE sprayed with drone at 300 g/ha followed by PSE at 250 g/ha, PSE at 200 g/ha applied with drone and PSE at 200 g/ha applied with knapsack sprayer registering weed density of 17.7, 20.7 and 22.0/m² respectively. All the above treatments were significantly superior over untreated control (174.0/m²), while PSE at 300 g/ha treatment also significantly superior to PSE at 150 g/ha and PSE at 100 g/ha registering weed densities of 35.3 and 47.0/m² respectively.

Weed density

Perusal of weed density data, 24 days after herbicide application during 2021 revealed that the weed density increased significantly in untreated control (416.0/m²) compared to all other treatments (Table 1). Among the treatments, the weed density at 24 DAHA ranged from 9.0 to 108.0/m², with significantly lowest in PSE at 300 g/ha followed by PSE at 250 g/ha applied through drone, PSE at 200 g/ha applied manually and PSE at 200 g/ha sprayed using drone with weed densities of 9.0, 14.0, 19.0 and 23.0/m² respectively. Out of all the PE weedicide treatments, significantly highest weed density was recorded with PSE at 100 g/ha (108/m²) and PSE at 150 g/ha (54/m²) and both were on par with each other.

During 2022, the weed density ranged from 10.0 to 79.0/m² among different PE weedicide treatments and all were significantly different and superior over untreated control (406.0/m²) out of these PSE at 300 g/ha with 10.0/m² weed density followed by PSE at

250 g/ha through drones, PSE at 200 g/ha manually applied using knapsack sprayer and PSE at 200 g/ha with drones with weed densities of 12.0, 13.0 and 20.0/m² respectively were on par and exercised better weed control over PSE at 15 g/ha and 100 g/ha (0.75x and 0.5x) with densities of 65.0 to 79.0/m² respectively. These results are in accordance with the previous studies (3 and 10) which stated that PE and PoE herbicide application by knapsack sprayer in both monocots and dicots weed density was at par with PE and PoE herbicide application by drone. These results are in accordance with early findings who reported that weed density of 78.3 (No./m²) by the application of bispyribac sodium using drone, while in manual spray recorded weed density of 74 (No./m²), weed free check (0.0) and unweeded check (183.3) during kharif, 2022 at Tamil Nadu (3).

Weed dry weight

The weed dry weight at 12 DAHA after application of PSE 10 % WP with drone varied significantly across different dates, but all the drone treatments were superior to untreated check. The weed dry weight ranged from 3.2 to 106.3 and 2.0 to 96.9 g/m² during 2021 and 2022 respectively at 12 DAHA (Table 2). Similarly, the weed dry weight varied from 2.9 to 142.3 g/m² and 2.1 to 109.3 g/m² at 24 DAHA during 2021 and 2022 respectively. Among the treatments, drone-based application of PSE at 200 g/ha (1.0x), PSE at 250 g/ha (1.25x) and PSE at 300 g/ha (1.5x) were found to exercise significant reduction of weed populations. Manual application of PSE at 200 g/ha was also equally effective at 1.0x dose. The untreated control (weedy check) accrued significantly higher weed populations ranging from 106.3 to 142.3 g/m² at 12 and 24 DAHA. These findings are in accordance with previous results reported that herbicides spraying using drone recorded lower weed dry weight at 1.0x dose (10). These results are consistent with early findings at Tamil Nadu observed that sequential application of pretilachlor fb by PoE bispyribac sodium using drone recorded a weed dry weight of 28.5 g/m² while same herbicide in manual spray recorded 27.3 g/m² but both were found to be on par (3).

Weed control efficiency

Weed control efficiency data of the above studies indicated that at 12 DAHA WCE ranged from 54.4–83.5 % and 66–82.8 % during 2021 and 2022 respectively (Table 3). At 24 DAHA the data showed that the WCE ranged from 54.2 to 83.3 % during 2021 and 49.5–83.8 %

Table 1. Impact of pre-emergence herbicide (pyrazosulfuron ethyl 10 %) applied through drone at different doses on weed density (No./m²) in wet direct seeded rice (WDSR)

Treatment details	12 DAHA		24 DAHA	
	2021	2022	2021	2022
T1: PSE 10 % WP at 100g/ha (0.5x) with drone	34.7 a (5.3)	47.0 b (6.9)	108.0 b (9.9)	79.0 b (8.9)
T2: PSE 10 % WP at 150g/ha (0.75x) with drone	17.0 a (3.8)	35.3 b (6.0)	54.0 b (7.2)	65.0 b (8.1)
T3: PSE 10 % WP at 200 g/ha (1.0x) with drone	18.3 a (3.8)	20.7 ab (4.6)	23.0 ab (4.8)	20.0 a (4.5)
T4: PSE 10 % WP at 250 g/ha (1.25x) with drone	23.3 a (4.9)	17.7 ab (4.3)	14.0 ab (3.9)	12.0 a (3.6)
T5: PSE 10 % WP at 300 g/ha (1.5x) with drone	16.7 a (3.9)	14.3 a (3.9)	9.0 a (2.9)	10.0 a (3.2)
T6: PSE 10 % WP at 200 g/ha (1.0x) with knapsack	19.0 a (3.9)	22.0 ab (4.8)	19.0 ab (4.3)	13.0 a (3.8)
T7: Untreated control (weedy check)	181.0 b (13.4)	174.0 c (13.1)	416.0 c (20.4)	406.0 c (20.2)
SE(m)±	1.3	0.6	1.3	0.4
CD at 5 % Significance Level	4.0	1.8	3.6	1.4
CV (%)	19.5	16.4	16.5	10.1

DAHA: days after herbicide application; WP: wettable powder; PSE: pyrazosulfuron ethyl; CD: critical difference; CV: coefficient of variation; Figures in parentheses are original value subjected to square root transformation ($\sqrt{x + 0.5}$).

Table 2. Influence of pre-emergence herbicide (pyrazosulfuron ethyl 10 %) applied through drone at different doses, on weed dry weight (g/m²) in wet direct seeded rice (WDSR)

Treatment details	12 DAHA		24 DAHA	
	2021	2022	2021	2022
T1: PSE 10 % WP at 100 g/ha (0.5x) with drone at 2.75 g/L of water	19.7 b (4.7)	9.7 b (3.3)	22.8 c (4.9)	30.4 b (5.3)
T2: PSE 10 % WP at 150 g/ha (0.75x) with drone at 4.13 g/L of water	6.3 a (2.5)	7.2 b (2.8)	10.1 b (3.3)	19.7 b (4.1)
T3: PSE 10 % WP at 200 g/ha (1.0x) with drone at 5.5 g/L of water	3.7 a (2.1)	3.1 a (2.0)	4.5 a (2.3)	3.8 ab (2.1)
T4: PSE 10 % WP at 250 g/ha (1.25x) with drone at 6.80 g/L of water	3.0 a (2.0)	2.2 a (1.8)	4.3 a (2.3)	3.6 ab (2.1)
T5: PSE 10 % WP at 300 g/ha (1.5x) with drone at 8.27 g/L of water	2.0 a (1.7)	2.0 a (1.7)	2.9 a (2.0)	2.1 a (1.7)
T6: PSE 10 % WP at 200 g/ha (1.0x) with knapsack at 0.4 g/L of water	3.2 a (2.0)	2.2 a (1.8)	4.4 a (2.3)	3.5 ab (2.1)
T7: Untreated control (weedy check)	106.3 c (10.3)	96.9 c (9.9)	142.3 d (12.0)	109.2 d (10.5)
SE(m)±	0.4	0.2	0.15	0.7
CD at 5 % Significance Level	1.3	0.5	0.5	2.3
CV (%)	19.2	8.7	6.1	12.1

DAHA: days after herbicide application; WP: wettable powder; PSE: pyrazosulfuron ethyl; CD: critical difference; CV: coefficient of variation; Figures in parentheses are original value subjected to square root transformation ($\sqrt{x + 0.5}$).

during 2022. It is evident from perusal of the data that treatments viz., PSE at 300 g, 250 g, 200 g/ha with drones and PSE at 200 g/ha with knapsack sprayer exercised effective and optimum weed control. These results corroborate with the previous findings which reported that herbicides sprayed using drone with 1.0x dose recorded higher weed control than 0.75x dose (10–11). There was no difference between knapsack and drone for the application of PE herbicide at 1x dose similar findings were reported (12).

Crop yield attributes and yield

Studies on the influence of pre-emergence herbicide (PSE 10 % WP) applied through drone at different doses on crop growth and yield in wet DSR system revealed that the tiller number varied from 314 to 455 and 335 to 424 tillers/m² during 2021 and 2022 respectively (Table 4). Significantly highest tiller number was noticed in PSE 10 % WP at 200 g/ha i.e., 1.0x dose applied using knapsack sprayer at 0.4g/L of water, the next best were T5: PSE 10 % WP at 300 g/ha (1.5 %) with drone at 8.27g/L of water and T3: PSE 10 % WP at 200 g/ha (1.0x) with drone at 5.5 g/L of water. The number of panicles per square metre during 2021 and 2022 also revealed similar trends with reduced panicle number. Similar results were reported in early studies (12, 13).

In terms of grain yield also significantly highest yield accrued with PSE 10 % WP at 200 g/ha (1.0x dose) with knapsack

sprayer (6094 and 6794 kg/ha) during the yield of 2021 and 2022 respectively (Table 5). This treatment was found to be on par with T3: PSE 10 % WP at 200 g/ha (1.0x) with drone at 5.5 g/L of water (1.0x dose with drone) and T4 (1.25x) and T5 (1.5x dose) and all these above treatments were found to be significantly superior over untreated control.

Higher grain yield in herbicide sprayed treatments could be attributed to efficient weed control that results in improved growth, yield attributes. Weed management reduced the weed density and weed dry weight hence plant could utilise the resources such as nutrients, light and water effectively and resulted in higher growth parameters and yield. Similar findings were reported in early research (13–16). The lowest rice yield was recorded in unweeded control, was due to high weed density and biomass that adversely affected all the yield parameters. Similar results were reported in previous studies (17–18).

Economics

The effectiveness of any production system is ultimately evaluated based on economics. Higher benefit cost (B:C) ratio was recorded (1.31) in T₃ (PSE 10 % WP at 200 g/ha (1.0x) with drone at 5.5 g/L of water) and T₆ (PSE 10 % WP at 200 g/ha (1.0x) with knapsack at 0.4 g/L of water) (1.31) and lower B : C ratio was

Table 3. Influence of pre-emergence herbicide (pyrazosulfuron ethyl 10 %) applied through drone at different doses, on weed control efficiency (WCE) in wet direct seeded rice (WDSR)

Treatment details	12 DAHA		24 DAHA	
	2021	2022	2021	2022
T1: PSE 10 % WP at 100 g/ha (0.5x) with drone	54.4	66.7	59.2	49.5
T2: PSE 10 % WP at 150 g/ha (0.75x) with drone	75.7	71.7	72.5	61.0
T3: PSE 10 % WP at 200 g/ha (1.0x) with drone	79.6	79.8	80.8	80.0
T4: PSE 10 % WP at 250 g/ha (1.25x) with drone	80.6	81.8	80.8	80.0
T5: PSE 10 % WP at 300 g/ha (1.5x) with drone	83.5	82.8	83.3	83.8
T6: PSE 10 % WP at 200 g/ha (1.0x) with knapsack	80.6	81.8	80.8	80.0
T7: Untreated control (weedy check)	0.0	0.0	0.0	0.0

DAHA: days after herbicide application; WP: wettable powder; PSE: pyrazosulfuron ethyl; CD: critical difference; CV: coefficient of variation; Figures in parentheses are original value subjected to square root transformation ($\sqrt{x + 0.5}$).

Table 4. Effect of pre-emergence herbicide (pyrazosulfuron ethyl 10 %) applied through drone at different doses on crop growth and yield in wet direct seeded rice (WDSR)

Treatment details	No. of tillers/m ²		No. of panicles/m ²		Grain yield (kg/ha)	
	2021	2022	2021	2022	2021	2022
T1: PSE 10 % WP at 100 g/ha (0.5x) with drone	333 ab	362 ab	275 a	299 a	4594 b	3687 b
T2: PSE 10 % WP at 150 g/ha (0.75x) with drone	352 ab	367 ab	307 ab	326 ab	4946 b	4043 b
T3: PSE 10 % WP at 200 g/ha (1.0x) with drone	428 bc	382 b	368 bc	365 b	5562 c	6190 c
T4: PSE 10 % WP at 250 g/ha (1.25x) with drone	392 b	399 b	359 b	389 b	5618 cd	6212 cd
T5: PSE 10 % WP at 300 g/ha (1.5x) with drone	455 bc	412 b	405 bc	382 b	5974 cd	6569 cd
T6: PSE 10 % WP at 200 g/ha (1.0x) with knapsack	478 c	424 b	426 c	407 b	6094 d	6794 d
T7: Untreated control (weedy check)	314 a	335 a	264 a	276 a	2885 a	2943 a
SE(m)±	22.6	14.5	20.0	17.1	178.2	203.1
CD at 5 % significance level	70.5	45.3	62.3	53.4	555	634
CV (%)	9.9	6.4	9.7	8.4	6.0	6.8

DAHA: days after herbicide application; WP: wettable powder; PSE: pyrazosulfuron ethyl; CD: critical difference; CV: coefficient of variation.

Table 5. Impact of pre-emergence herbicide (pyrazosulfuron ethyl 10 %) applied through drone at different doses, on economics

Treatment details	12 DAHA		24 DAHA	
	2021	2022	2021	2022
T1: PSE 10 % WP at 100 g/ha (0.5x) with drone	53717	32230	0.97	0.96
T2: PSE 10 % WP at 150 g/ha (0.75x) with drone	61151	39759	1.09	1.07
T3: PSE 10 % WP at 200 g/ha (1.0x) with drone	74764	89641	1.31	1.30
T4: PSE 10 % WP at 250 g/ha (1.25x) with drone	74690	88762	1.28	1.27
T5: PSE 10 % WP at 300 g/ha (1.5x) with drone	77460	89447	1.30	1.28
T6: PSE 10 % WP at 200 g/ha (1.0x) with knapsack	81867	98450	1.31	1.30
T7: Untreated control (weedy check)	15321	16695	0.29	0.28

WP: wettable powder; PSE: pyrazosulfuron ethyl;

noticed with un weeded control (0.29) as crop faced higher competition for resources throughout the crop growing period.

The herbicide application cost was comparatively more for knapsack (12 to 23 %) than drone application. It was attributed to increased labour wages, water and time for herbicide application. The crop maintenance cost can be decreased up to 20 % when drones and diploid for pesticide application (19–21). Similar findings were reported in early research (22, 23).

Conclusion

In wet direct seeded rice (WDSR) where the management of the weed menace is crucial for reaping higher yields, weed control efficiency (WCE) was higher spraying of pre emergence herbicide using manual spray however it require lot of human energy, pre emergence (PE) herbicide can be sprayed in WDSR using drones with 1x dose found better in term of weed density, weed dry weight and WCE. Further it is noticed that decreasing the herbicide dose per unit area was not advisable as the WCE was very poor with 0.5x dose and 0.75x dose and drastically effected rice yields.

All-inclusive, the present study supports the safety and effectiveness of the selected treatments in WDSR and unrealised benefits of using drone technology for weed management. Further studies can be done on the utilisation of drone technology for weed management can be done by appraising herbicide drift and strategies to minimise off target repercussions.

Acknowledgements

The authors are thankful to Institute of Rice Research, Agricultural Research station, PJTAU, Telangana, India for facilities provided. The work was financially supported by the NABARD, Telangana, India.

Authors' contributions

PSB carried out the experiment, performed the data analysis and wrote the original draft. PRRR conceptualised and supervised the work and contributed to the review of the manuscript. NRGV carried out data retention and interpretation. TKB assisted in improving the content. PSB was involved in data annotation and curation. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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