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Assessment of Post Emergence Herbicide Efficacy for Drone Spraying in Transplanted Rice (*Oryza sativa* L.)

L. Naveen [a*], P. Spandana Bhatt [b++], K. Bhanu Rekha [c#] and T. Ramprakash [d†]

[a] College of Agriculture, PJTSAU, Hyderabad, Telangana, India.
[b] Institute of Rice Research, Rajendranagar, Hyderabad, India.
[c] College of Agriculture, PJTSAU, Rajendranagar, Hyderabad, Telangana, India.
[d] AICRP on Weed Management (DJB), Rajendranagar, Hyderabad, India.

Authors' contributions

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

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ABSTRACT

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 among different doses of herbicidal treatments, post emergence application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1}using drone recorded highest number of tillers at harvest, plant height at harvest, number of panicles at harvest, grain yield and low weed dry matter at 60 DAT. It was statistically on par with application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i

[++] *Scientist (Agronomy);*
[#] *Associate Professor (Agronomy);*
[†] *Principal Scientist & Head;*
**Corresponding author: E-mail: naveenlakavath1998@gmail.com;*

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.

Keywords: Herbicide efficacy; transplanted rice; global grain.

1. 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" [1]. "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" [2].

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. [3] 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".

Manual weeding is cumbersome and uneconomical due to labour scarcity and increased labour cost. It consumes more time and drudgery due to walking in the puddled field with tank load and spraying, which is hindering the weed control efficiency. In the current scenario of high labour costs and non-availability of labour for manual weeding, use of herbicides is inevitable. To face these challenges, advanced technology should be used in agriculture to save time and energy. Drone being a modern technology can be solution for farmers. Agricultural drones provide relief for the modern-day farmers to reduce drudgery and to act timely for crop needs.

"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" [4].

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 [5,6]. Drones are a potential alternative for aerial chemical spraying due to their high adaptability [4]. 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.

2. 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_2O5, 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 40liter 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.

3. RESULTS AND DISCUSSION

3.1 Effect on Crop

3.1.1 Plant height at harvest (cm)

At harvest significantly higher plant height (cm) was recorded with T_6 (weed free hand weeding at 20, 40 and 60 DAT) and it was statistically at par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer), T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone). T_7 (unweeded control) plot recorded significantly lower plant height over all the treatments. Increased plant height in weed management practices compared to unweeded control treatment might be due to reduced weed competition for light, water and nutrients *etc,.*The increased plant height in PoE sprayed plots either by using drone at recommended or higher doses and knapsack sprayer was due to better weed control coupled with favorable soil environment which might have resulted in reduced crop weed competition for the growth factors such as light, space and wind which supported prolonged photosynthetic activity for assimilation of nutrients resulting in increased plant height (Uphoof, 2001), Paul et al. [7].

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

At harvest the maximum number of tillers were recorded with T_6 (Hand weeding at 20, 40 and 60 DAT) and it was statistically at par with T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer) followed by T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) and it was statistically at par with T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1}using drone). Treatment T_7 (Unweeded control) was recorded significantly lower number of tillers (m^{-2}) due to higher crop weed competition significantly lower over all the treatments. These results are in line with Yakadri et al. [8], Rana et al. [9] and Venkatesh et al*.* (2019). (Table 3).

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

Table 2. Plant height at harvest (cm)

Treatments	Plant height at harvest
T_1: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer.	113.2
T_2: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone.	101.0
T_3: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone.	108.9
T_4: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone.	110.2
T_5: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone.	114.7
T_6: Weed free (Hand weeding at 20, 40 and 60 DAT)	115.8
T_7: Unweeded control	90.6
SE(m)±	2.2
CD (P=0.05)	6.9

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

Significantly higher number of panicles (m^{-2}) was noticed in T_6 (weed free hand weeding at 20, 40 and 60 DAT) 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), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer), T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone). Significantly lower number of panicles (m^{-2}) was recorded under T_7 (unweeded coontrol). This was due to severe competition exerted by weeds for space, light and nutrients throughout the crop growth period [10]. Number of panicles at harvesting time is a vital determinant of grain yield in rice. However, the variation in panicles (m^{-2}) among weed management practices studied was closely related to tiller production as the total number of panicles in a unit area is a product of the number of plants established and the number of tillers produced by each plant. Therefore, the higher panicle number could be traced to higher tiller production.

The different weed control methods significantly exert influence on number of panicles. In rice the number of panicles recorded in herbicide treatments ranged from 292 m^{-2} to 222 m^{-2}. The highest number of panicles were recorded among herbicidal treatements T_5 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1} using drone) and it was comparable with application of PoE by drone and knapsack sprayer at recommended dose and higher dose except at the lower dose of the herbicidal treatment with drone *i.e,* T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone) (222 m^{-2}). The results were in conformity with findings of Paul et al. [7].

3.1.4 Grain yield (kg ha^{-1})

Rice grain yield was significantly higher with T_6 (weed free hand weeding at 20, 40 and 60 DAT) 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), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using knapsack sprayer), T_4 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1} using drone) and T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone) 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). Significantly the lowest grain yield was registered with T_7 (unweeded control).

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

Table 3. Number of tillers (m^{-2}) at harvest

Treatments	Number of tillers at harvest
T_1: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1}using knapsack sprayer.	365
T_2: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.iha^{-1}using drone.	284
T_3: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.iha^{-1}using drone	348
T_4: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.iha^{-1}using drone.	351
T_5: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.iha^{-1}using drone.	381
T_6: Weed free (Hand weeding at 20, 40 and 60 DAT)	392
T_7: Unweeded control	203
SE(m)±	7.2
CD (P=0.05)	31.4

Table 4. Number of panicles (m^{-2}) at harvest

Treatments	Number of panicles at harvest
T_1: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1}using knapsack sprayer.	289.2
T_2: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1}using drone.	222.6
T_3: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1}using drone	275.1
T_4: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1}using drone.	282.8
T_5: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1}using drone.	292.0
T_6: Weed free (Hand weeding at 20, 40 and 60 DAT)	309.3
T_7: Unweeded control	134.5
SE(m)±	12.3
CD (P=0.05)	38.1

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 severaly effected the grain yield (4653 kg ha^{-1}) (T_2). Paul et al. [7].

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 [11,12,13] and Ramesha et al. [14].

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. (2019).

3.2 Effect on Weeds

3.2.1 Weed dry matter (g m^{-2}) 60DAT

At 60 DAT, significantly lower total weed dry weight was observed with T_6 (weed free hand weeding at 20, 40 and 60 DAT) 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), T_1 (application of penoxsulam 1.02% + cyhalofop-butyl 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 T_3 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using drone). It was followed by T_2 (application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1} using drone), Significantly higher total weed dry weight was recorded with T_7 (unweeded control).

After the treatment imposition at 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 severaly 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

Table 5. Grain yield (kg ha^{-1})

Treatments	Grain yield
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.iha^{-1}using drone.	4653
T_3: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.iha^{-1}using drone	6029
T_4: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.iha^{-1}using drone.	6186
T_5: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.iha^{-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

Table 6. Weed dry matter (gm^{-2}) 60 DAT

Treatments	Weed dry matter 60 DAT
T_1: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1}using knapsack sprayer.	3.97 (14.80)
T_2: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 90 g a.i ha^{-1}using drone.	5.73 (31.80)
T_3: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1}using drone	4.59 (20.10)
T_4: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 150 g a.i ha^{-1}using drone.	4.27 (17.20)
T_5: Application of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 180 g a.i ha^{-1}using drone.	3.95 (14.60)
T_6: Weed free (Hand weeding at 20, 40 and 60 DAT)	3.75 (13.10)
T_7: Unweeded control	11.69 (135.60)
SE(m)±	0.29
CD (P=0.05)	0.88

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

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 [7].

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 [7,15-20].

4. CONCLUSION

Assessment of post emergence herbicide application for drone spraying in transplanted rice experiment was conducted to study the effect of different doses of herbicides on weed control, crop growth and yield. Based on the results, the following conclusions were drawn.

- The effects of applying the recommended dose of penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @ 120 g a.i ha^{-1} using a knapsack sprayer or a drone were recorded on par weed density and weed control efficiency. This suggests that drones can be deployed for the spraying of post-emergence herbicides.
- The highest rice yield was recorded in T_6 (Hand weeding thrice), which was comparable to the post-emergence herbicide using either a drone or a knapsack sprayer.
- Results of this experiment showed that dose of herbicide application using drones had also a significant effect on all the measured traits. Reduced doses of herbicide (90 g a.i ha^{-1}) could not controlled weeds and gave significantly decreased yield, while Increasing the dose from 120 g a.i ha^{-1} to 180 g a.i ha^{-1} ended in on par WCE and yield. Hence, it was found that while using the drones, herbicide must be applied at recommended dose.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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