Indian Journal of Agricultural Sciences **93** (7): 704–709, July 2023/Article
https://doi.org/10.56093/ijas.v93i7.137859

Drone-based herbicide application for energy saving, higher weed control and economics in direct-seeded rice (*Oryza sativa*)

R AROCKIA INFANT PAUL[1]*, P MURALI ARTHANARI[2], S PAZHANIVELAN[1], R KAVITHA[1] and M DJANAGUIRAMAN[1]

Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641 003, India

Received: 16 June 2023; Accepted: 06 July 2023

ABSTRACT

A field experiment was conducted at Tamil Nadu Agricultural University, Coimbatore during *kharif* (rainy) and *rabi* (winter) seasons of 2022 and 2023 to evaluate the efficiency, energy and economics of drone-based herbicide application in direct-seeded rice (*Oryza sativa* L.). The study was carried out with application of pre-emergence, early post-emergence and post-emergence herbicides using drone and knapsack sprayer to assess the weed control efficiency. Treatments included pretilachlor followed by (*fb)* application of post-emergence herbicides, such as bispyribac-sodium (Na), fenoxyprop ethyl + carfentrazone ethyl and early post-emergence herbicides, such as bispyribac-Na, fenoxyprop ethyl + carfentrazone ethyl, bispyribac-Na *fb* post-emergence of fenoxyprop ethyl + carfentrazone ethyl, weed-free check and unweeded check. Application of pretilachlor *fb* bispyribac-Na using knapsack sprayer reduced weed density from 83 to 87% and weed dry weight from 81 to 83% over unweeded plot. Moreover, it was found on par with drone application of same herbicides in both seasons. Pretilachlor *fb* bispyribac-Na application through knapsack sprayer and drone produced higher grain yield and it was comparable with weed-free plot. Higher net return, benefit: cost ratio (2.27 and 2.09), energy-use efficiency (10.86 and 9.55 MJ) and energy productivity (0.81 and 0.71 kg/MJ) were noticed with drone application of pretilachlor *fb* bispyribac-Na in both the seasons. From the experiment, drone application of pretilachlor *fb* bispyribac-Na is found as an effective strategy to manage weeds in direct-seeded rice and more advantageous in terms of energy-use and profitability.

Keywords: Direct-seeded rice, Drone, Energy, Herbicide, UAV, Weed control efficiency

Resources (water, energy, labour and capital) are the crucial factors which influence the crop production. Agricultural labours are considerably shifting into non-agricultural sector (Srivastava *et al.* 2020) 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). Therefore, the development of drone technologies for pesticide application is essential for the efficient management of scarce resources with remunerative energy, yield and returns. Conventional transplanting of rice (*Oryza sativa* L.) is confronted with a range of scarce resources. Hence, there is a positive trend towards the adoption of direct-seeded rice (DSR) as it offers several advantages, especially water saving and reduction in green-house gas emissions. However, the grain yield is severely influenced by weed infestation (Dass *et al.* 2017, Pratap *et al.* 2021). Rice production without adoption of weed control measures resulted in average yield loss of 40 to 80% in DSR (Sunil *et al.* 2010).

Hand weeding is a traditional and efficient method for weed control but it is labour and energy-intensive and often not economical. In DSR, weed management accounts for largest share of energy and capital used. Chemical weed management is one of the efficient and alternative methods to hand weeding (Pratap *et al.* 2021). However, single herbicide is not effective to manage diversified weed flora in DSR. Hence, judicious and right combination of herbicide is essential for better weed control. Conventionally, knapsack sprayers are the preferred method for chemical application in farm operations. However, it encompasses several constraints such as, shortage of trained labour and high risk of herbicide exposure (Cao *et al.* 2017). Moreover, conventional sprayer consumes more time, energy, water, labour and drudgery for herbicide application. To reduce the overuse of resources, drones are the alternative technology for herbicide application with limited resources. However, there was very limited research on the efficiency of herbicides by drone application. Hence, the present study

[1]Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu; [2]ICAR-Krishi Vigyan Kendra, Tamil Nadu Agricultural University, Sirugamani, Tamil Nadu. *Corresponding author email: raipaul307@gmail.com

was carried out to i) evaluate the efficiency of drone-based herbicide application for weed control ii) compare the economics and energy use for weed control using drone in direct-seeded rice.

MATERIALS AND METHODS

The field experiments were conducted at research farm of Tamil Nadu Agricultural University, Coimbatore (11°54'N and 76°56' E with an altitude of 426.7 meters amsl), Tamil Nadu during *kharif* (August to November, 2022) and *rabi* (November to March, 2022–2023) to evaluate the suitable herbicide combinations for weed control under drone application. The experiment was laid-out in a randomized block design with 3 replications and 12 weed control treatments. Treatments included drone and knapsack application of pretilachlor followed by (*fb)* application of post-emergence herbicides, such as bispyribac sodium, fenoxyprop ethyl + carfentrazone ethyl and early post-emergence herbicides, such as bispyribac sodium, fenoxyprop ethyl + carfentrazone ethyl, bispyribac sodium *fb* post-emergence of fenoxyprop ethyl + carfentrazone ethyl, weed-free check and unweeded check.

Manual hand weeding was done to maintain the plot as weed-free check. Drone application of pretilachlor (450 g a.i/ha), bispyribac sodium (35 g a.i/ha) and tank-mix fenoxyprop ethyl (67.5 g a.i/ha) + carfentrazone ethyl (20 g a.i/ha) were done with different spray volumes of 40 litre/ha, 30 litre/ha and 60 litre/ha respectively. Similarly, all herbicides were applied using knapsack sprayer with spray volume of 500 litre/ha. The pre-emergence pretilachlor was applied at 3 days after sowing (DAS), early post-emergence herbicides at 12 to 20 DAS and post-emergence herbicides at 20 to 25 DAS. Flat fan nozzle was used in both sprayer and silicon based non-ionic surfactant (5 ml/10 L) was added in early-post and post-emergence application.

Speed, effective swath and height of drone-based pre-emergence herbicide application were 4 m/s, 3 m and 1 m, respectively and 5 m/s, 4 m and 1.5 m, respectively for post-emergence herbicides. The drone was flown twice with same operational parameters to achieve application volume of post-emergence herbicide fenoxyprop ethyl + carfentrazone ethyl. Meanwhile, the knapsack sprayer operational parameters used were speed (0.34 to 0.41 m/s and 0.26 to 0.37 m/s), effective swath (2 m) and height (0.42 to 0.50 m and 0.44 to 0.56 m) for pre-emergence and post-emergence herbicides, respectively. Moreover, similar operational parameters of post-emergence herbicides were adopted for early post-emergence herbicides.

The rice variety used for the experiment was CO 51. Sprouted seeds were sown by using a drum seeder with a spacing of 20 cm × 10 cm. The recommended dose of fertilizer 150:50:50 kg/ha of N: P_2O_5: K_2O was adopted. The weed parameters (weed density, weed dry weight and weed control efficiency) were observed at 40 DAS. Weed density was recorded in 4 quadrants (0.5 m × 0.5 m) placed randomly in each plot. Weed control efficiency (WCE) was calculated as (Mani *et al.* 1973):

$$\text{WCE (\%)} = \frac{\text{Weed dryweight in control plot- weed dryweight in treated plot}}{\text{Weed dryweight in control plot}} \times 100$$

Yield parameters (grain yield and straw yield) were recorded from a net plot area and expressed in kg/ha at 14% moisture. Different economic indices, viz. gross return, net return and benefit-cost ratio (BCR) were calculated based on prevailing market price of the input and output. The energy values for all the inputs and outputs were taken based on published energy conversion coefficients (Devasenapathy *et al.* 2009). Energy output from produce (grain and straw) was calculated by multiplying the quantity of production with its energy equivalent. Energy efficiency per cent was calculated by dividing output energy by input energy. The ratio between yield and energy was determined by energy productivity. The difference between output energy and input energy gives the value of net energy.

The two season data was statistically analyzed as suggested by Gomez and Gomez (1984). Statistical significance was tested by F test at a critical difference (CD) of 0.05 level of probability. The data on weed density and weed dry weight were subjected into square root transformation $\sqrt{(X+0.5)}$ before statistical analysis. Relationships between grain yield and weed dry weight was assessed using linear regression analysis (IBM SPSS statistics software version 26.0).

RESULTS AND DISCUSSION

Weed flora of the experimental site: The dominant weed flora found in the experimental field consisted of *Echinochloa colona, Echinochola crugalli, Leptochloa chinensis, Cyperus difformis, Bergia capensis*, *Ludwigia parviflora* in both seasons. *Monochoria vaginalis* was found in *kharif* season and *Ammannia baccifera* and *Eclipta alba* were found in *rabi* season.

Weed density, weed dry weight and weed control efficiency: The relative density of the experimental site was dominated by grasses (41.1%) followed by broadleaf weeds (35.6%) and sedges (23.3%) during *kharif* season. Meanwhile, *rabi* season was dominated by broadleaf weeds (38.2%) followed by sedges (32.2%) and grasses (29.6%). Pre-emergence, early post-emergence and post-emergence herbicides application using drone and knapsack showed a sound effect on the total weed density, weed dry weight and WCE during both seasons (Table 1). The highest total weed density (183.33 and 193.67 weeds/m^2 during *kharif* and *rabi*, respectively) and weed dry weight (147.53 and 143.66 g/m^2 during *kharif* and *rabi*, respectively) were recorded in unweeded check. All weed management treatments significantly reduced the total weed density and weed dry weight compared with unweeded control. The lowest total weed density was recorded in sequential application of herbicides using both drone and knapsack sprayer. Among the treatments, the lowest total weed density (31.67 and 25.67 weeds/m^2 during *kharif* and *rabi*, respectively), weed dry weight (24.26 and 27.35 g/m^2 during *kharif* and *rabi*, respectively) and highest weed control efficiency were recorded with application of pretilachlor *fb* bispyribac sodium in knapsack sprayer and it was on par with drone application in both seasons. Application of pre-emergence pretilachlor offered broad spectrum of weed control at initial stage and attributed for higher grain yield (Sangeetha *et al.* 2009). Similarly, subsequent flush of weeds was effectively controlled by application of bispyribac sodium (Soren *et al.* 2017, Chinnamani *et al.* 2018). In addition, sequential application of herbicides was significantly effective in reducing weed density and dry weight than weedy check in both application (drone and knapsack sprayer). However, weed infestation observed in single application of early post-emergence bispyribac sodium or tank-mix fenoxaprop ethyl + carfentrazone ethyl plot was significantly higher than plots treated with sequential application of herbicides during both seasons. There was no significant difference between both application (drone and knapsack) in all the herbicide combinations and confirmed that the reduced quantity of carrier volume was not affected the herbicide efficacy. Similar control efficacy of drone was due to increased droplet deposition on the abaxial surface of weed foliage compared to conventional sprayer (Martin *et al.* 2020). Chen *et al.* (2019) reported that herbicide mixtures (isoproturon + clodinafop-propargyl + mesosulfuron) applied through drone on wheat had similar weed control efficiency with conventional knapsack sprayer.

Effect of weed control on yield attributes: The different weed control methods significantly exert influence on grain yield (Fig 1). Rice grain yield recorded in all herbicide treatments ranged from 4462 to 5944 and 4031 to 5653 kg/ha, while unweeded plot yielded 3122 and 2915 kg/ha during *kharif* and *rabi*, respectively. The highest grain yield (5944 kg/ha and 5653 kg/ha during *kharif* and *rabi*, respectively) was recorded in the plots treated with pre-emergence pretilachlor *fb* post-emergence bispyribac sodium using knapsack sprayer and it was comparable with drone application of pretilachlor *fb* bispyribac sodium and pretilachlor *fb* tank-mix fenoxaprop ethyl + carfentrazone ethyl and bispyribac sodium *fb* tank-mix fenoxaprop ethyl + carfentrazone ethyl in both applications. Plots treated with the single herbicide (bispyribac sodium or tank-mix

Table 1 Effect of drone based application of herbicides on weed control in rice

Treatment	Weed density (Weeds/m²)		Weed dry matter (g/m²)		Weed control efficiency per cent	
	kharif	*rabi*	*kharif*	*rabi*	*kharif*	*rabi*
PE pretilachlor *fb* POE bispyribac sodium drone spray	5.84 (33.67)	5.43 (29.00)	5.20 (26.55)	5.38 (28.55)	82.0	80.1
PE pretilachlor *fb* POE fenoxyprop ethyl + carfentrazone ethyl drone spray	6.11 (37.33)	6.38 (40.33)	5.61 (31.01)	6.09 (36.65)	78.9	74.4
EPOE bispyribac sodium drone spray	8.88 (78.33)	9.01 (80.67)	7.62 (57.59)	8.95 (79.66)	60.9	44.5
EPOE fenoxyprop ethyl + carfentrazone ethyl drone spray	7.56 (57.00)	8.11 (65.33)	7.46 (55.20)	9.14 (83.12)	62.5	42.1
EPOE bispyribac sodium *fb* POE fenoxyprop ethyl + carfentrazone ethyl drone spray	5.99 (35.67)	6.28 (39.00)	5.62 (31.18)	6.39 (40.36)	78.8	71.9
PE pretilachlor *fb* POE bispyribac sodium manual spray	5.65 (31.67)	5.11 (25.67)	4.97 (24.26)	5.27 (27.35)	83.5	80.9
PE pretilachlor *fb* POE fenoxyprop ethyl + carfentrazone ethyl manual spray	6.00 (35.67)	5.81 (33.33)	5.68 (31.85)	6.06 (36.26)	78.4	74.7
EPOE bispyribac sodium manual spray	8.63 (74.00)	8.70 (75.33)	7.53 (56.20)	8.93 (79.31)	61.9	44.7
EPOE fenoxyprop ethyl + carfentrazone ethyl manual spray	7.47 (55.33)	7.28 (52.67)	7.49 (55.81)	8.62 (73.79)	62.1	48.6
EPOE bispyribac sodium *fb* POE fenoxyprop ethyl + carfentrazone ethyl manual spray	6.05 (36.67)	6.45 (41.33)	5.51 (29.92)	6.25 (38.63)	79.7	73.1
Weed-free check	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	100	100
Unweeded check	13.56 (183.33)	13.93 (193.67)	12.16 (147.53)	12.00 (143.66)	-	-
SEd	0.37	0.36	0.27	0.22	-	-
CD (P=0.05)	0.77	0.75	0.55	0.45	-	-

Data in the parenthesis are original value, which was transformed into $\sqrt{(X+0.5)}$.

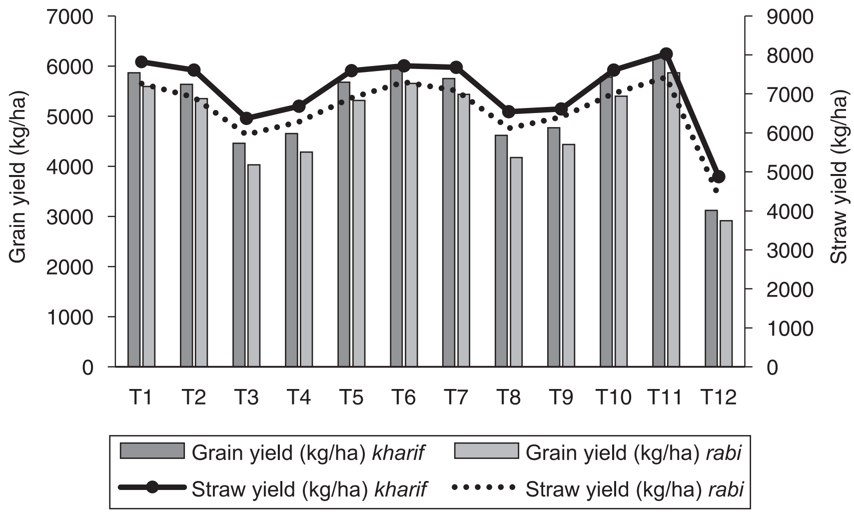

Fig 1 Effect of drone herbicide application technology on grain and straw yield in rice.

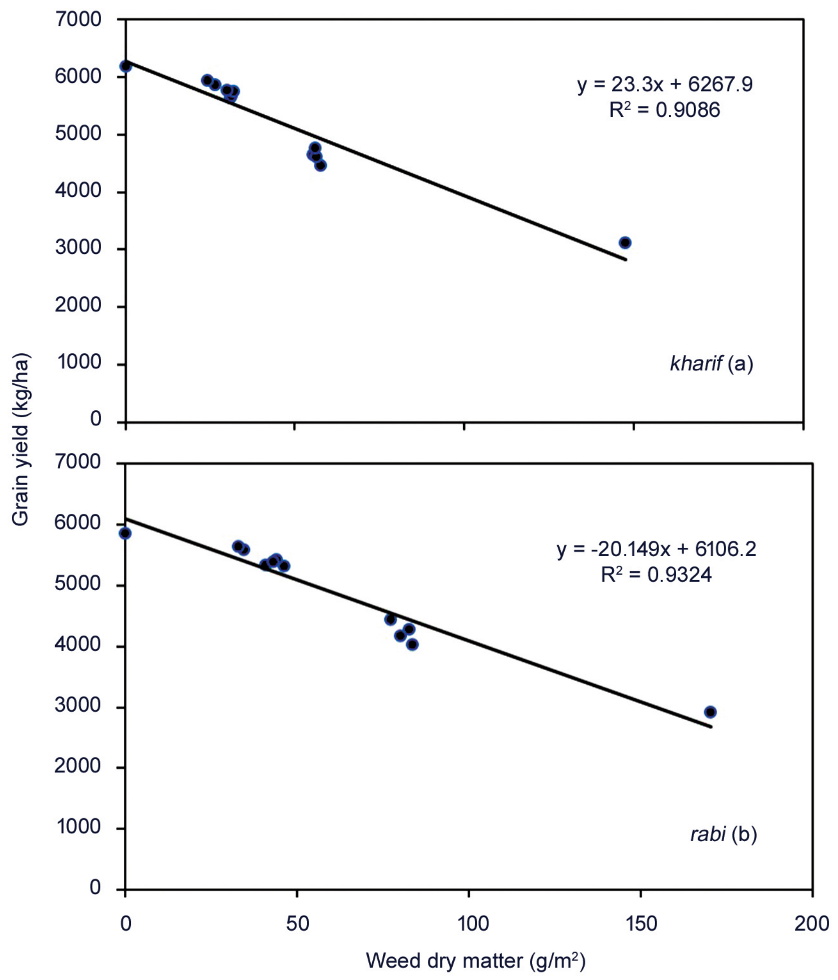

Fig 2 Correlation between weed dry matter and grain yield in rice.

fenoxaprop ethyl + carfentrazone ethyl) had significantly lower yield (25 to 29%) than sequential herbicide treated plots. Similarly, the sequential application of herbicides resulted in better straw yield than other treatments in both application methods. The result was corroborated with findings of Mahajan and Chauhan (2015) and reported that sequential application of pendimethalin *fb* fenoxaprop ethyl produced better yield than single application of either pendimethalin or fenoxaprop ethyl.

Correlations between weed dry weight and grain yield: In both seasons, a strong negative linear correlation was found between weed dry weight and grain yield. Similar results were reported by Ansari *et al.* (2017). Weed dry weight had strong relationship with grain yield than weed density (Fig 2). The relationship indicated that, grain yield of rice was reduced up to 28 to 31% if the weed dry matter was more than 50–70 g/m^2 during both seasons in single herbicide treated plots. Sequential application of pretilachlor *fb* bispyribac sodium through knapsack and drone application resulted in better weed control and grain yield than other treatments. The weed dry weight was more than 140 g/m^2, and grain yield was reduced to 50% in unweeded plot. The findings indicate that weed posed high competition to rice crops for the resources and resulted in poor yield in unweeded plot. The results were corroborated with findings of Kumar *et al.* (2018) and stated that yield reduction caused by weeds in DSR is more than 56% in the weedy plot.

Economics: The highest additional cost for weed control was recorded in weed-free plot (₹27000/ha) and lowest with drone application of bispyribac sodium (₹3683/ha) (Table 2). The cost varied for the application of herbicides from 3683 to 8438 ₹/ha for drone application and 4538 to 9488 ₹/ha for knapsack sprayer. The result indicated that the application cost was comparatively more for knapsack (12 to 23%) than drone application. It was attributed to increased labour wages for herbicide application. Garre and Harish (2018) reported that the production cost can be reduced up to 20% through drone application of pesticides. The highest grain yield and gross return were recorded in weed-free check. However, the high incurred cost for weed control resulted in lesser net return and benefit cost ratio (BCR) than all herbicide treated plots. The highest net return (₹59067/ha and ₹52235/ha during *kharif* and *rabi*, respectively) and BCR (2.27 and 2.09 during *kharif* and *rabi*, respectively) were obtained in drone application of pretilachlor *fb* bispyribac sodium. The result of herbicide combinations was in line with earlier

Table 2 Effect of drone herbicide application technology on economics of rice

Treatment	Additional cost (₹/ha)	Gross return (₹/ha)		Net return (₹/ha)		B:C	
		Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
PE pretilachlor *fb* POE bispyribac sodium drone spray	6777	105593	100111	59067	52235	2.27	2.09
PE pretilachlor *fb* POE fenoxyprop ethyl + carfentrazone ethyl drone spray	7984	101752	95621	54018	46537	2.13	1.95
EPOE bispyribac sodium drone spray	3683	81595	74299	38163	29517	1.88	1.66
EPOE fenoxyprop ethyl + carfentrazone ethyl drone spray	4800	85211	78842	40661	32942	1.91	1.72
EPOE bispyribac sodium *fb* POE fenoxyprop ethyl + carfentrazone ethyl drone spray	8438	102246	95109	54058	45571	2.12	1.92
PE pretilachlor *fb* POE bispyribac sodium manual spray	7782	106385	101063	58854	52182	2.24	2.07
PE pretilachlor *fb* POE fenoxyprop ethyl + carfentrazone ethyl manual spray	8194	103528	97399	55584	48105	2.16	1.98
EPOE bispyribac sodium manual spray	4538	84266	76777	39979	31140	1.90	1.68
EPOE fenoxyprop ethyl + carfentrazone ethyl manual spray	4950	86622	81371	41922	35321	1.94	1.77
EPOE bispyribac sodium *fb* POE fenoxyprop ethyl + carfentrazone ethyl manual spray	9488	103765	96609	54527	46021	2.11	1.91
Weed-free check	27000	110718	104360	43968	36260	1.66	1.53
Unweeded check	0	58338	53946	18588	12846	1.47	1.31

Fixed cost for *kharif*-₹39750, *rabi*-₹41100.

Table 3 Effect of drone herbicide application technology on energy analysis of rice

Treatment	Additional input energy (MJ/ha)	Output energy (MJ/ha)		Energy-use efficiency		Energy productivity (kg/MJ)	
		Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
PE pretilachlor *fb* POE bispyribac sodium drone spray	459.47	183974	173044	10.86	9.55	0.81	0.71
PE pretilachlor *fb* POE fenoxyprop ethyl + carfentrazone ethyl drone spray	624.43	177978	165026	10.40	9.02	0.77	0.67
EPOE bispyribac sodium drone spray	98.83	145287	133709	8.76	7.53	0.65	0.56
EPOE fenoxyprop ethyl + carfentrazone ethyl drone spray	263.79	151976	141512	9.08	7.89	0.68	0.59
EPOE bispyribac sodium *fb* POE fenoxyprop ethyl + carfentrazone ethyl drone spray	362.62	178362	164333	10.59	9.12	0.79	0.68
PE pretilachlor *fb* POE bispyribac sodium manual spray	674.05	183914	174437	10.72	9.51	0.80	0.71
PE pretilachlor *fb* POE fenoxyprop ethyl + carfentrazone ethyl manual spray	835.41	180519	168551	10.42	9.11	0.78	0.68
EPOE bispyribac sodium manual spray	325.38	149697	137838	8.91	7.66	0.66	0.57
EPOE fenoxyprop ethyl + carfentrazone ethyl manual spray	486.74	152794	145373	9.00	8.01	0.67	0.60
EPOE bispyribac sodium *fb* POE fenoxyprop ethyl + carfentrazone ethyl manual spray	629.54	180126	167048	10.53	9.13	0.78	0.68
Weed-free check	471	191278	179011	11.28	9.87	0.84	0.73
Unweeded check	0	106836	97584	6.48	5.52	0.49	0.41

Common input energy for *kharif*-16482.89 MJ, *rabi*-17663.84 MJ.

findings of Patel *et al.* (2018). The lowest net return and BCR were recorded in unweeded check because of poor grain and straw yield.

Energy analysis: Different weed management treatments caused significant variations in different indices of energy balance (Table 3). The highest input energy for herbicide treatments ranged from 98.83 MJ/ha to 624.43 MJ/ha for drone application and 325.38 MJ/ha to 835.41 MJ/ha for knapsack application. The requirement of input energy was comparatively higher for knapsack sprayer than drone application. Among the weed management treatments, highest output energy (183974 and 173044 MJ/ha), energy use efficiency (10.86 and 9.55) and energy productivity (0.81 and 0.77 kg/MJ) during *kharif* and *rabi* were recorded in drone application of pretilachlor *fb* bispyribac sodium. It was resulted due to drone application of herbicides effectively reduces the use of excess energy inputs, viz. water, electricity and labour for weed control than knapsack methods.

Overall, the study demonstrated that drone application of pre-emergence pretilachlor followed by post-emergence bispyribac sodium significantly reduced the weed density, weed dry weight and recorded the highest grain and straw yield in DSR. In addition, maximum net return, benefit-cost ratio, output energy, energy use efficiency and energy productivity were recorded in the drone application than knapsack application. Hence, application of pretilachlor followed by bispyribac sodium through drone might be recommended to obtain higher productivity with more remunerative energy and income in direct-seeded rice.

ACKNOWLEDGEMENTS

The authors acknowledge the International Rice Research Institute, Philippines and Tamil Nadu Agricultural University, Coimbatore for funding to carry out this research work as well as financial support from INSPIRE fellowship, facilitated by the Department of Science and Technology, Government of India.

REFERENCES

Ansari M, Yadav R, Siddiqui M, Ansari M, Khan N, Mishra D and Husain K. 2017. Efficacy of crop establishment techniques and weed control measures on weed dynamics, weed control efficiency and productivity in rice (*Oryza sativa*). *Indian Journal of Agricultural Sciences* **87**(8): 1084–88.

Cao L, Cao C, Wang Y, Li X, Zhou Z, Li F, Yan X and Huang Q. 2017. Visual determination of potential dermal and inhalation exposure using allura red as an environmentally friendly pesticide surrogate. *ACS Sustainable Chemistry and Engineering* **5**: 3882–89.

Chen Y, Qi H, Li G and Lan Y. 2019. Weed control effect of unmanned aerial vehicle (UAV) application in wheat field. *International Journal of Precision Agricultural Aviation* **2**(2): 31.

Chinnamani I, Aasif M, Kumar N S, Velayutham A and Suresh S. 2018. Influence of weed management practices on weed dynamics and yield of drum seeded rice under puddled condition. *International Journal of Advances in Agricultural Science and Technology* **5**(7): 17–23.

Dass A, Shekhawat K, Choudhary, Anil K, Sepat S, Rathore S S, Mahajan G and Chauhan B S. 2017. Weed management in rice using crop-competition. *Crop Protection*. **95**: 45–52.

Devasenapathy P, Senthilkumar G and Shanmugam P. 2009. Energy management in crop production. *Indian Journal of Agronomy* **54**(1): 80–90.

Garre P and Harish A. 2018. (*In*) *Autonomous agricultural pesticide spraying UAV, IOP Conference Series: Materials Science and Engineering* **455**(012030): 1–3.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research,* 2nd edn. International Rice Research Institute, P. O. Box. Manila Philippines and John wiley and sons, New York, USA.

Kumar S, Shivani J, Mishra J, Kumar S and Bharati R. 2018. Efficacy of pre-and post-emergence herbicides on complex weed flora in direct-seeded rice (*Oryza sativa*) in the eastern plains. *Indian Journal of Agricultural Sciences* **88**(3): 387–92.

Mahajan G and Chauhan B. 2015. Weed control in dry direct-seeded rice using tank mixtures of herbicides in South Asia. *Crop Protection* **72**: 90–96.

Mani V, Malla M and Gautam K C. 1973. Weed-killing chemicals in potato cultivation. *Indian farming* **23**(8): 17–18.

Martin D, Singh V, Latheef M A and Bagavathiannan M. 2020. Spray deposition on weeds (Palmer amaranth and Morningglory) from a remotely piloted aerial application system and backpack sprayer. *Drones* **4**(59): 1–18.

Patel T U, Lodaya D H, Italiya A P, Patel D D and Patel H H. 2018. Bio-efficacy of herbicides in direct-seeded rice. *Indian Journal of Weed Science* 50(2): 120–23.

Pratap V, Verma S K, Dass A, Yadav D K, Jaysawal P K and Madane A J. 2021. Productivity, economics and resource-use efficiency of direct seeded rice (*Oryza sativa* L.) under varying crop establishment methods and weed management practices. *Indian Journal of Agricultural Sciences* **91**(4): 537–41.

Sangeetha S P, Balakrishnan A, Priya R S and Maheswari J. 2009. Influence of seeding methods and weed management practices on direct seeded rice. *Indian Journal of Weed Science*. **41**(3&4): 210–12.

Soren C, Bera S, Mukhopadhyay S and Saren D. 2017. Bio-efficacy and phytotoxicity studies of Bispyribac Sodium 10% SC in direct seeded rice. *Journal of Crop and Weed* **13**(3): 165–67.

Srivastava S K, Singh J, Kumar N R, Singh N P and Ahmad N. 2020. Changing agricultural labour market and its effects on farm economy in India. *Indian Journal of Agricultural Economics* **75**(4): 469–80.

Sunil C M, Shekara B G, Kalyanmurthy K N and Shankaralingapa B C. 2010. Growth and yield of aerobic rice as influenced by integrated weed management practices. *Indian Journal of Weed Science* **42**(3&4): 180-83.

Vaishnavi P and Manisankar G. 2022. Labour scarcity in agriculture: A review. *The Pharma Innovation Journal* **11**(4): 2087–90.