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RESEARCH NOTE

Comparison of UAV and knapsack herbicide application methods on weed spectrum, crop growth and yield in dry direct-seeded rice

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ABSTRACT

A field experiment was conducted to compare the Unmanned Aerial Vehicle (UAV) and knapsack herbicide application on the diverse weed flora, growth and yield attributes of dry-direct seeded rice in randomized block design replicated thrice during 2023 at Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal, Puducherry UT, India. Grasses dominated the weed flora, with 80.5% relative density of *Echinochloa colona*. UAV spray volume at 50 L/ha with application of pendimethalin + penoxsulam on 3 DAS 625 g/ha *fb* bispyribac-sodium on 20 DAS 25 g/ha reduced total weed density (39.4/m^2) and biomass (23.4 g/m^2), resulted better rice growth (plant height and tillers/plant), yield parameters (panicle weight and 1000 grain weight) and yield (3.87 t/ha). Negative linear relationship was observed between rice grain yield and total weed biomass at harvest stage. Uncontrolled weeds caused 65.6% yield loss in dry-DSR of the coastal deltaic ecosystem.

Keywords: Dry direct seeded rice, Herbicide dose, Unmanned aerial vehicle, Weed management

Rice (*Oryza sativa* L.) is the foremost staple food, sustains over half the world population. Conventional transplanted rice is cumbersome, demands huge amount of labour, energy, water and deteriorates soil health due to repeated tillage and puddling operations (Ojha and Kwatra 2014). So, direct-seeded rice (DSR) constitutes an emerging approach, where rice seeds are directly sown into dry soil, bypassing the need for water-filled nurseries and transplanting. One major challenge of DSR method is weed growth due to the absence of standing water. To tackle this, various weed management strategies were practiced. Initially, single application of herbicide became popular due to labour unavailability. But later, sequential application of herbicides proved more effective in sustaining weed suppression throughout the critical growth phase (Saravanane 2020) than single application.

Normally, manual knapsack sprayers were used to apply herbicides, requiring significant amounts of water, energy and time. Moreover, knapsack sprayers require higher spray liquid which leads to herbicide wastage. During recent times, Unmanned Aerial Vehicle (UAV) spray technology for herbicide applications emerges as a promising alternative to optimize the resource usage. This approach minimized herbicide wastage, water consumption, time investment and energy expenditure (Supriya *et al*. 2021) and increased the efficiency of herbicides making an efficient method for herbicide application. However, the utilization of UAVs is a new concept for spraying both pre- and post-emergence herbicides in this coastal region and the volume of efficient spray fluid was not standardized in dry-DSR for weed management practices. Hence, a field experiment was conducted to evaluate the efficacy of varying weed management options in UAV compared with standardized knapsack spray to manage the weeds in direct-seeded rice at Karaikal, Puducherry UT, India.

A field experiment was conducted at eastern research farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry UT (10° 552 N latitude and 79° 492 E longitude, 4 m above mean sea level), India during February – April 2023 (Navarai season). The rainfall distribution is furnished in **Figure 1**. The soil was neutral in pH (6.61) with the texture of sandy clay loam, low in available N (141.1 kg/ha), high in available P (31.8 kg/ha) and medium in available K (188.8 kg/ha).

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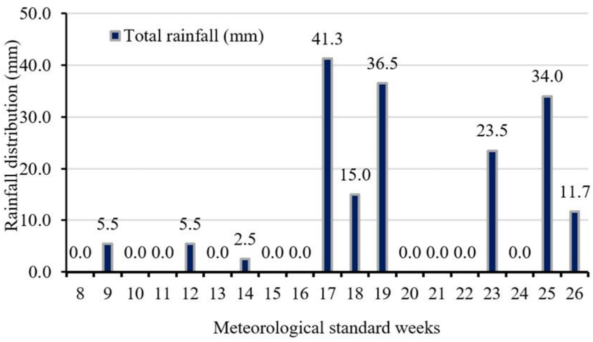

Figure 1. Rainfall prevailed during the cropping period from February to June 2023

The experiment was arranged in randomized block design replicated thrice with twelve treatments of varying spray fluids for UAV spray at 25, 50, 75 and 100 L/ha and knapsack spray fluid at 500 L/ha. Each spray fluid consisted of two herbicide concentrations, *viz*. 75% HRD (pendimethalin + penoxsulam on 3rd DAS at 468.8 g/ha *fb* bispyribac-sodium on 20th DAS at 18.8 g/ha) and 100% HRD (pendimethalin + penoxsulam on 3rd DAS at 625 g/ha *fb* bispyribac-sodium on 20th DAS at 25 g/ha). It also included hand weeding twice at 20 and 40 DAS and unweeded control.

Rice (cultivar '*ASD 16*' with duration of 110 days) was sown on the fourth week of February and harvested during the fourth week of June. Experimental area was ploughed twice using tractor-drawn cultivator and was levelled with power tiller for even water distribution, respectively. Germination test was conducted to determine the seed viability on the *ASD 16* certified seed, sown on petri dish and subsequently evaluated after 3 days. The results indicated average germination rate of 96.0%, highlighting the tested seeds to sprout and develop into healthy plants. Manual seeding was done with seed rate of 75 kg/ha, adopting a spacing of 15 cm x 10 cm and covered with soil. The size of the experimental plots was 12 m x 3.9 m. The field was surface irrigated immediately after the sowing with the water available in the farm ponds, to have enough moisture at pre-emergence herbicide application. Herbicides were applied using UAV and knapsack sprayer both fitted with a flat fan nozzle with water as a spray fluid at 25, 50, 75 and 100 L/ha for UAV and 500 L/ha for knapsack sprayer on both herbicide concentrations (75 and 100% herbicide recommended dose (HRD). Hand weeding was carried out in the experimental plots using hand hoe at 20 and 40 DAS. Entire quantity of phosphorus (50 kg/ha), ¼th of nitrogen (37.5 kg/ha) and ½ of potassium (25 kg/ha) were applied basal. Remaining nitrogen was applied in three equal splits starting from 15 DAS, maximum tillering stage and flowering stage. The remaining ½ of potassium was applied in two splits along with N at the maximum tillering stage and flowering stage, respectively. Pre-emergence and post-emergence herbicides were used as per the treatment. The data on weed density and dry matter accumulation were recorded at 60 DAS using quadrate size of 0.5 m x 0.5 m (Saravanane 2020) placed at two random places in each plot and the relative density (RD) was computed using standard formula. Weeds were uprooted at ground level during weed observation at 60 DAS, washed with running water, sun-dried, oven-dried at 70°C for 48 h, and then weighed to record weed biomass. Rice grain yield was measured from the net plot leaving the border rows and expressed in t/ha at 14% moisture content.

The data on weed density and dry weight was transformed to square root transformation ($\sqrt{x + 0.5}$) to normalize their distribution before analysis. Grain yield and weed biomass relationships at harvest were assessed using linear regression analysis. The experimental data were subjected to standard statistical analysis (Panse and Sukhatme, 1967).

Weed floristic composition

Experimental field infested with diverse weed flora comprised of five grasses (*Echinochloa colona*, *Echinochloa crus-galli*, *Dactyloctenium aegyptium*, *Leptochloa chinensis* and *Panicum repens*), eight broad-leaved weeds (*Cleome viscosa*, *Aeschynomene indica*, *Corchorus tridens*, *Eclipta alba*, *Ludwigia parviflora*, *Phyllanthus niruri*, *Sphaeranthus indicus* and *Trianthema portulacastrum*) and three sedges (*Cyperus difformis*, *Cyperus iria* and *Fimbristylis miliacea*) at 60 days after sowing (DAS). Analysis of the relative density revealed that *Echinochloa colona* was major weed species (80.5%) in the experimental field which was followed by *Cleome viscosa* (4.5%), *Leptochloa chinensis* (3.4%) and *Fimbristylis miliacea* (2.9%). This study revealed that dry DSR extremely favoured the growth of *Echinochloa colona* in the experimental field as it is an annual C_4 grass which made it heavy competitor for solar radiation, capacity to withstand high temperatures and required less moisture regime that made it dominant than any other weed species. The results also corroborated the finding of Wang *et al*. (2019). Nguyen *et al*. (2016) have suggested that higher temperatures made *E. colona* harder to control in less moisture regime.

Weed density, biomass and weed control efficiency

The weed density of all weed species was lowered in herbicide applied plots. But, *Echinochloa colona* density has significantly reduced in UAV spray of 50 and 25 L/ha with 100% HRD (36.7 and 47.3

weeds/m^2) and the density reduction was found to be 89.4 and 86.4% compared to the unweeded control (347.3 weeds/m^2) (**Table 1**). Lower spray fluid volumes result in more concentrated, potentially enhancing its effectiveness in inhibiting germinating weeds. The spray fluid of 25 and 50 L/ha were lower which made the herbicide dosage more concentrated compared to 75, 100 and 500 L/ha. Moreover, coverage under the spray fluid in 50 L/ha was better than 25 L/ha to cover the entire field. When pendimethalin + penoxsulam, a synergistic herbicide (Mann *et al*. 2016) was applied to the soil, it was absorbed via root hairs, which inhibited microtubule formation in weeds and controlled the weeds, particularly *E. colona*. Similar result was found by Khalik and Matloob (2012). When the bispyribac sodium (hydrophilic) was applied on the foliage, the presence of hydrophilic pectin strands in leaves made herbicide absorption easier. This inhibited the ALS pathway in post-emerged weeds. Similar result was aligned with Saravanane (2020) with the application of pendimethalin followed by bispyribac-sodium would effectively control the weeds, particularly *E. colona*.

The weed biomass of all weed species was reduced in herbicide applied plots. But, biomass of *Echinochloa colona* (22.2 and 25.3 g/m^2) had decreased significantly in UAV spray of 50 and 25 L/ha with 100% HRD and the biomass reduction was found to be 84.2 and 82.0% compared to the unweeded control (**Table 2**). The spray fluid of 25 and 50 L/ha was lower which made the herbicide dosage more concentrated compared to 75, 100 and 500 L/ha that effectively controlled the weeds. This led to reduction in weed biomass in the experimental field. However, the spray fluid of 25 L/ha was not sufficient to cover the entire field. Whereas, higher biomass was under unweeded control plots due to the absence of weed management practices leading to establishment of new weeds and resulting in higher accumulation of essential resources like sunlight, water and nutrients. Similar results were obtained with the findings of Pooja and Saravanane (2021) and Pavithra *et al*. (2021).

Weed control efficiency was influenced due to weed biomass recorded in various treatments (**Table 2**). Higher weed control efficiency (85.2%) was recorded in UAV spray of 50 L/ha with 100% HRD, which was followed by UAV spray of 25 L/ha with 100% HRD (83.5%). Comparatively, 100% HRD effectively controlled the weeds than 75% HRD because the dosage reduction did not effectively control the weeds in UAV and knapsack spray. Similar result obtained by Supriya *et al*. (2021) when the herbicide concentration was reduced for UAV application. The results of current study are also in

Table 1. Effect of various weed management treatments on weed density at 60 DAS in dry direct-seeded rice

Treatment	Weed density (no./m^2)							
	E. colona	*L. chinensis*	Other grasses	*F. miliacea*	Other sedges	*C. viscosa*	Other BLW	Total weeds
UAV spray of 25 L/ha with 75% of HRD	8.15 (66.0)	0.71 (0.0)	1.48 (1.7)	0.71 (0.0)	1.10 (0.7)	0.71 (0.0)	0.71 (0.0)	8.30 (68.4)
UAV spray of 25 L/hawith 100% of HRD	6.92 (47.3)	1.35 (1.3)	1.34 (1.3)	1.35 (1.3)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	7.19 (51.2)
UAV spray of 50 L/ha with 75% of HRD	8.11 (65.3)	1.08 (0.7)	1.58 (2.0)	1.68 (2.3)	1.22 (1.0)	0.71 (0.0)	0.71 (0.0)	8.47 (71.3)
UAV spray of 50 L/ha with 100% of HRD	6.10 (36.7)	0.71 (0.0)	1.79 (2.7)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	6.32 (39.4)
UAV spray of 75 L/ha with 75% of HRD	10.95 (119.3)	0.71 (0.0)	0.71 (0.0)	1.68 (2.3)	1.34 (1.3)	0.71 (0.0)	0.71 (0.0)	11.11 (122.9)
UAV spray of 75 L/ha with 100% of HRD	9.16 (83.3)	1.47 (1.7)	1.87 (3.0)	0.71 (0.0)	1.58 (2.0)	0.71 (0.0)	0.71 (0.0)	9.51 (90.0)
UAV spray of 100 L/ha with 75% of HRD	9.86 (96.7)	1.08 (0.7)	1.58 (2.0)	0.71 (0.0)	1.34 (1.3)	1.96 (3.3)	1.10 (0.7)	10.26 (104.7)
UAV spray of 100 L/ha with 100% of HRD	9.16 (83.3)	1.87 (3.0)	2.35 (5.0)	1.78 (2.7)	1.58 (2.0)	0.71 (0.0)	0.71 (0.0)	9.82 (96.0)
Knapsack spray of 500 L/ha with 75% of HRD	14.18 (200.7)	2.27 (4.7)	3.10 (9.1)	0.71 (0.0)	0.71 (0.0)	2.68 (6.7)	1.34 (1.3)	14.93 (222.5)
Knapsack spray of 500 L/ha with 100% of HRD	12.51 (156.0)	1.08 (0.7)	2.43 (5.4)	1.87 (3.0)	0.71 (0.0)	0.71 (0.0)	1.10 (0.7)	12.90 (165.8)
Hand weeding twice at 20 and 40 DAS	11.91 (141.3)	2.20 (4.3)	2.76 (7.1)	1.08 (0.7)	2.81 (7.4)	0.71 (0.0)	1.10 (0.7)	12.73 (161.5)
Unweeded control	18.65 (347.3)	3.89 (14.7)	6.44 (41.0)	3.58 (12.3)	3.39 (11.0)	4.45 (19.3)	2.86 (7.7)	21.30 (453.3)
LSD (p=0.05)	3.4	1.3	1.4	1.2	0.8	1.3	0.6	3.2

agreement with earlier findings of better weed suppression with proper use of sequential application of pre- and post-herbicides in DSR (Saravanane 2020 Pooja and Saravanane 2021).

Growth, yield attributes, yield and weed index

Implementing weed management measures led to better growth and yield attributes compared to the unweeded control (**Table 3**). Application of UAV spray at a rate of 50 L/ha with a 100% HRD resulted in increased plant height by 24.9 per cent (118.8 cm) compared to the unweeded control (95.1 cm). When weeds left uncontrolled, could induce stress on rice crops by competing for resources and hindering overall plant growth (Dass *et al*. 2017). Furthermore, UAV spray at 50 L/ha led to 40.4 percent increase in tillers (8.7 tillers per plant) compared to the unweeded control (6.2 tillers per plant), indicating improved tiller production due to reduced competition for resources among rice crops. Dass *et al*. (2017) agreed rice in weed-free plots exhibited higher tiller production due to the absence of weed competition.

Table 2. Effect of various weed management treatments on weed biomass and weed control efficiency at 60 DAS in dry direct-seeded rice

Treatment	Weed biomass (g/m^2)								WCE (%)
	E. colona	*L. chinensis*	Other grasses	*F. miliacea*	Other sedges	*C. viscosa*	Other BLW	Total weeds	
UAV spray of 25 L/ha with 75% of HRD	6.24 (38.4)	0.71 (0.0)	1.10 (0.7)	0.71 (0.0)	0.77 (0.1)	0.71 (0.0)	0.71 (0.0)	6.30 (39.2)	75.2
UAV spray of 25 L/hawith 100% of HRD	5.08 (25.3)	1.00 (0.5)	0.84 (0.2)	0.77 (0.1)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	5.16 (26.1)	83.5
UAV spray of 50 L/ha with 75% of HRD	5.94 (34.8)	0.87 (0.3)	1.10 (0.7)	0.77 (0.1)	0.77 (0.1)	0.71 (0.0)	0.71 (0.0)	6.04 (36.0)	77.2
UAV spray of 50 L/ha with 100% of HRD	4.76 (22.2)	0.71 (0.0)	1.30 (1.2)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	4.89 (23.4)	85.2
UAV spray of 75 L/ha with 75% of HRD	7.29 (52.7)	0.71 (0.0)	0.71 (0.0)	1.00 (0.5)	0.77 (0.1)	0.71 (0.0)	0.71 (0.0)	7.33 (53.3)	66.3
UAV spray of 75 L/ha with 100% of HRD	6.56 (42.6)	1.02 (0.5)	1.10 (0.7)	0.71 (0.0)	0.89 (0.3)	0.71 (0.0)	0.71 (0.0)	6.68 (44.1)	72.1
UAV spray of 100 L/ha with 75% of HRD	7.01 (48.6)	0.84 (0.2)	1.22 (1.0)	0.71 (0.0)	0.84 (0.2)	0.95 (0.4)	0.77 (0.1)	7.14 (50.5)	68.1
UAV spray of 100 L/ha with 100% of HRD	6.98 (48.3)	1.29 (1.2)	0.95 (0.4)	1.00 (0.5)	0.89 (0.3)	0.71 (0.0)	0.71 (0.0)	7.16 (50.7)	67.9
Knapsack spray of 500 L/ha with 75% of HRD	8.64 (74.1)	1.45 (1.6)	1.92 (3.2)	0.71 (0.0)	0.71 (0.0)	0.95 (0.4)	0.77 (0.1)	8.94 (79.4)	49.8
Knapsack spray of 500 L/ha with 100% of HRD	7.08 (49.7)	1.32 (1.2)	1.97 (3.4)	0.77 (0.1)	0.71 (0.0)	0.71 (0.0)	0.78 (0.1)	7.41 (54.5)	65.6
Hand weeding twice at 20 and 40 DAS	5.38 (28.4)	1.12 (0.8)	1.70 (2.4)	0.77 (0.1)	1.70 (2.4)	0.71 (0.0)	0.77 (0.1)	5.88 (34.2)	78.4
Unweeded control	11.88 (140.7)	2.28 (4.7)	1.61 (2.1)	1.41 (1.5)	2.07 (3.8)	2.02 (3.6)	1.48 (1.7)	12.59 (158.1)	–
LSD (p=0.05)	2.5	0.7	0.4	0.3	0.4	0.4	0.2	2.5	

Table 3. Effect of various weed management treatments on growth, yield and weed index in dry direct-seeded rice

Treatment	Plant height (cm)	Productive tillers/plant	Panicle weight (g)	1000 seed weight (g)	Grain yield (t/ha)	Weed index
UAV spray of 25 L/ha with 75% of HRD	113.9	8.5	2.7	22.0	3.39	12.1
UAV spray of 25 L/ha with 100% of HRD	114.9	8.5	2.8	22.3	3.66	5.3
UAV spray of 50 L/ha with 75% of HRD	117.1	8.7	2.8	22.2	3.40	11.6
UAV spray of 50 L/ha with 100% of HRD	118.8	8.7	2.8	22.9	3.87	–
UAV spray of 75 L/ha with 75% of HRD	110.9	8.4	2.4	22.0	2.92	24.2
UAV spray of 75 L/ha with 100% of HRD	105.7	8.0	2.4	22.0	3.22	16.1
UAV spray of 100 L/ha with 75% of HRD	110.6	8.2	2.5	21.9	2.83	26.3
UAV spray of 100 L/ha with 100% of HRD	112.6	7.1	2.8	21.7	3.12	18.7
Knapsack spray of 500 L/ha with 75% of HRD	111.7	8.2	2.0	21.8	2.82	26.6
Knapsack spray of 500 L/ha with 100% of HRD	109.5	8.0	2.6	21.4	2.92	24.4
Hand weeding twice at 20 and 40 DAS	109.2	7.1	2.4	21.7	2.71	29.8
Unweeded control	95.1	6.2	1.8	21.4	1.33	65.6
LSD (p=0.05)	6.2	0.8	0.6	NS	0.3	–

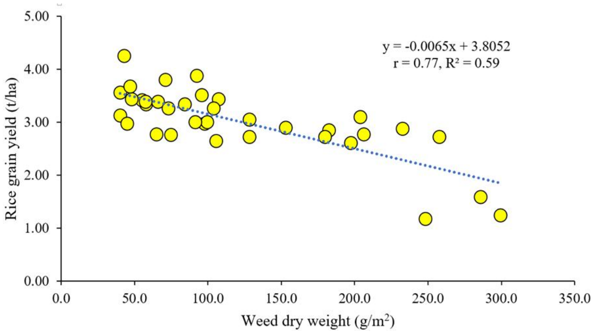

Figure 2. Relationship between grain yield and weed biomass at harvest stage in dry direct-seeded rice

UAV spray of 50 L/ha with 100% HRD significantly increased the grain yield compared to unweeded control. The efficient suppression of weed growth in 50 L/ha, enhanced nutrient absorption, higher interception of sunlight resulting in greater resource allocation of photosynthates to the yield-attributes, thus it increased the grain yield. Findings of Awan *et al.* (2015) proved higher grain yield was due to pre- and post-emergence herbicide application. Lower yield was recorded in unweeded control plots due to dense weed growth. Panicle weight was higher in UAV spray of 50 L/ha with 100% HRD and on par with UAV spray of 25 L/ha with 100% HRD (2.8 g). The response for 1000 grain weight was not significant among each other (**Table 3**). Poor filling and less panicle weight in unweeded control may be due to strong crop-weed competition for nutrient, space, light and carbon dioxide (Dass *et al.* 2017). The scatter plot reveals a strong negative correlation (r = 0.77, R^2 = 0.59, almost 0.60) between rice grain yield and weed dry weight, indicating that as weed dry weight increases, rice grain yield significantly decreases (**Figure 2)**. Application of UAV spray at 50 L/ha at 100 % HRD recorded lower weed index due lower weed density, biomass and higher weed control efficiency. But, when weeds were left uncontrolled throughout the growing season, pulled down the yield of dry-seeded rice to 65.6%. Earlier, yield losses due to weeds in dry direct seeded rice in coastal deltaic ecosystem were recorded from 51.9 to 93.1% (Pooja and Saravanane 2021 Saravanane 2020 Pavithra *et al.* 2021). When the spray volume decreased, drift also decreased and vice versa. Although controlling drift within the adjacent plot was challenging, it was manageable beyond the distance. Hence, using a lower spray volume can effectively control drift. Similar findings by Dengeru *et al.* (2022) indicated a significant reduction in drift after 5 meters from the treatment plot.

It was concluded that farmers can opt UAV spray of 50 L/ha with application of pendimethalin + penoxsulam on 3 DAS 625 g/ha *fb* bispyribac-sodium on 20 DAS 25 g/ha to effectively manage the diverse weed flora and enhance the rice yield of dry direct seeded rice in the coastal deltaic ecosystem of Karaikal, Puducherry UT.

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