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RESEARCH NOTE

Effect of herbicide application by unmanned aerial vehicle (UAV) on diverse weed flora, summer cotton growth, yield and economics

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ABSTRACT

A field experiment was conducted during February to July 2024 at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry, to study the effect of herbicide application using Unmanned Aerial Vehicle (UAV) on the diverse weed flora, cotton growth, yield and economics. The experiment consisted of seven treatments, *viz.* pre-emergence application (PE) of pendimethalin 1.0 kg/ha using UAV with spray volume of 25, 37.5, 50 L/ha; pendimethalin 1.0 kg/ha PE using knapsack sprayer with spray volume of 500 L/ha water, inter-cultivation twice at 20 and 45 days after seeding (DAS), inter-cultivation twice followed by (*fb*) manual weeding at 60 DAS and unweeded control. A randomized block design with three replications was used. The grasses were dominant in the experimental plot, with 57.8 % relative density of *Echinochloa colona*. Pendimethalin 1.0 kg/ha on 3 DAS using UAV with a spray volume of 37.5 L/ha resulted in greater reduction in total weed density and biomass with better cotton growth (plant height), yield parameters (number of bolls/plant, boll weight), yield, higher net return and benefit:cost ratio. Uncontrolled weeds caused 87.7 % yield loss in summer cotton of the coastal deltaic ecosystem.

Keywords: Cotton, Economics, Pendimethalin, Spray volume, Unmanned aerial vehicle, Weed management

In India, cotton is a major commercial crop, also known as '*White Gold*' or the '*King of Fibers*' It is an important cash crop that holds a significant position in global agriculture and the industrial economy. It is a long-duration, widely spaced crop that grows slowly in its early stages which is prone to severe weed infestations. Weeds that grow alongside cotton plants cause intense competition and yield reduction to an extent of 50 to 85% (Singh *et al*. 2022). Cotton with minimal weed competition during the early phase, up to 60 days, tends to yield better. To overcome weeds challenge, several weed management practices were developed to achieve effective weed control including the usage of pre-emergence herbicides in the early period of the cotton growth.

Traditionally, manual knapsack sprayers have been used to apply herbicides which consume considerable amounts of energy, time and labour. Additionally, knapsack sprayer usage requires a higher volume of spray liquid and lead to herbicide wastage. Recently, unmanned aerial vehicle (UAV) spray technology has emerged as an ideal alternative for the optimization of resources for herbicide applications as it was found to reduce herbicide wastage, water usage, time, and energy (Supriya *et al.* 2021), while increasing herbicide efficacy, making it a more effective approach for herbicide application. However, the use of UAVs in herbicide application is still novel, and the proper volume of spray liquid for effective weed management in summer cotton are yet to be standardized. Therefore, a field experiment was conducted to evaluate the efficacy of UAV sprayer usage to apply recommended pre-emergence herbicide for managing diverse weed flora in summer cotton of the coastal deltaic ecosystem, Karaikal, Puducherry UT, India.

A field experiment was carried out at Eastern Research Farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry UT, India (10° 55' N latitude and 79° 49' E longitude, 4 meters above mean sea level), during February to July 2024 (Summer). The rainfall distribution pattern of the field site is depicted in **Figure 1**. The soil was neutral in pH (6.72) with the texture of sandy clay loam, low in available N (156.8 kg/ha), high in available P (38.8 kg/ha) and medium in available K (176.0 kg/ha). The experiment was arranged in randomized block design with three replications. Seven treatments were included, *viz*. pre-emergence application (PE) of pendimethalin 1.0 kg/ha using UAV spray with spray volume of 25, 37.5, 50 L/ha; and pendimethalin 1.0 kg/ha PE using knapsack spray with spray volume of 500 L/ha; inter-

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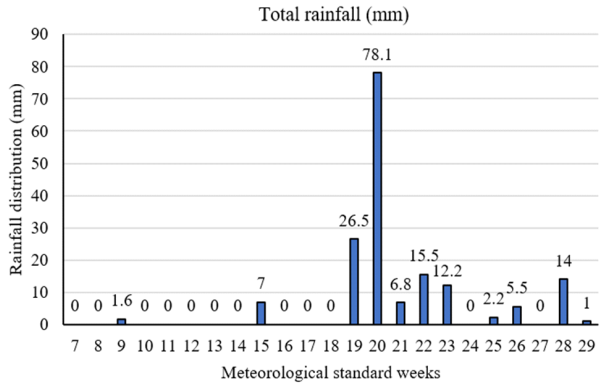

Figure 1. Rainfall prevailed during the cropping period from February to July 2024

cultivation (IC) twice at 20 and 45 days after seeding (DAS); IC twice *fb* manual weeding at 60 DAS and un-weeded control. The pendimethalin 1.0 kg/ha PE (38.7 % CS) was sprayed on 3 DAS. Inter-cultivation twice was carried out using power tiller at 20 and 45 DAS. Further, a common inter-cultivation was carried out in the experimental plots using power tiller at 20 DAS in all pre-emergence pendimethalin sprayed experimental plots. Preceding to cotton, rice crop was cultivated in the experimental fields. After the harvest of rice, experimental area was ploughed twice using tractor- drawn cultivator and then, rotavator was used to break up soil clumps and create a fine, level field for sowing. Cotton Hybrid '*RCH 659 BG II*' (with duration of 160 days) seed was sown during the fourth week of February and harvested during the fourth week of July in 2024. Manual seeding was done using 2.4 kg/ha of seed rate, with 90 cm x 60 cm spacing. The size of the experimental plots was 10.8 m x 8.1 m. The field was surface irrigated immediately after sowing operation to ensure sufficient moisture for the application of pre-emergence herbicide.

The UAV used for herbicide application was hexacopter in nature, equipped with a 10 L tank capacity. It was fitted with four flat fan nozzles, ensuring uniform spray distribution with a spray height of 1 m, with water as a spray fluid using spray volume of 25, 37.5 and 50 L/ha for UAV and the spray speed varies with spray fluid *i.e.*, speed of 7.4, 4.4, 2.7 m/s respectively, and 500 L/ha water was used for spraying pendimethalin 1.0 kg/ha with knapsack sprayer. Entire quantity of phosphorus (60 kg/ha), 50 % of nitrogen and potash were applied basally. The remaining half dose were applied in two equal splits at 45 DAS and 65 DAS. Weed density and dry weight (biomass) data were collected at 80 DAS using a 0.5 m x 0.5 m quadrat (Saravanane 2020). The quadrat was placed at two randomly selected locations within each plot, and the relative density (RD) determined using a standard calculation formula. Weeds were uprooted at ground level during the weed observation at 80 DAS, washed with running water, shade-dried, oven-dried at 70°C for 48 h, and then weighed to determine the weed biomass. Seed cotton yield was measured from the net plot leaving the border rows and expressed in kg/ha. The cost of commercial formulation of pendimethalin used in the study was Rs.650/litre. The drone rental cost during the study period was Rs.400/ac. Based on input, output and drone rental cost, economic indices like gross return, net return, and benefit-cost ratio (BCR) were computed.

The data on weed density and biomass were square root transformed ($\sqrt{x+0.5}$) to normalize their distribution before analysis. The relationship between seed cotton yield and weed biomass at harvest was evaluated using linear regression analysis. The experimental data were analyzed using standard statistical methods (Panse and Sukhatme 1967).

Weed flora

Diverse weed flora was observed in the experimental field including grasses, sedges, broad-leaved weeds and volunteer rice (*Oryza sativa*). Totally nine species of weeds belonging to six families were observed including: three grasses (*Echinochloa colona*, *Dactyloctenium aegyptium* and *Leptochloa chinensis*); one sedge (*Cyperus iria*) and four broad-leaved weeds (*Cleome viscosa*, *Corchorus tridens*, *Phyllanthus niruri* and *Trianthema portulacastrum*). *Echinochloa colona* Link. dominated the weed flora with higher relative density (57.8%) which was followed by *Cleome viscosa* L. (11.4%), *Dactyloctenium aegyptium* (7.0%) and *Trianthema portulacastrum* L. (6.5%). The growth of *Echinochloa colona* in the experimental field was abundant, as it is a troublesome annual C_4 grass with its early flowering ability (Hegazy *et al.* 2005) and further, resilience to high temperatures grant it a competitive advantage over other weeds, especially in dryland conditions common in cotton cultivation. The volunteer rice was also observed in the experimental plot (**Table 1**) due to the use of combined harvesters in preceding rice harvest which lead to shattering of rice seeds and the germination of volunteer rice in the succeeding cotton crop.

Weed density, biomass and weed control efficiency

The density of all the weed species was drastically reduced with pendimethalin application except volunteer rice. Pendimethalin sprayed with both knapsack and UAV sprayers was ineffective in suppressing volunteer rice since pendimethalin herbicide is the recommended selective herbicide in

dry direct-seeded rice (Rao 2007, Saravanane 2020). *Echinochloa colona* density and biomass were significantly reduced in UAV spray of 37.5 L/ha with a reduction in the density and dry weight of 84.9 and 95.7%, respectively when compared to the unweeded control (**Table 1**). When pendimethalin was applied to the soil, it was absorbed via root hairs, which inhibited microtubule formation in weeds and effectively controlled the weeds (Saravanane 2020), particularly *Echinochloa colona*. Lower spray fluid volume resulted in more concentrated spray which would potentially increase its effectiveness in suppressing germinating weeds. The spray fluid volume of 37.5 L/ha was lower, leading to a higher herbicide concentration compared to 50 and 500 L/ ha, which eventually resulted in effective suppression of weeds and higher weed control efficiency (95.9 %) at 80 DAS. However, higher herbicide concentration under lower spray fluid volume of 25 L/ha resulted in reduced weed control efficiency (89.8 %) which might be due to high operation speed of UAV (7.4 m/s) under low spray volume resulting in poor coverage of experimental field as observed by Karthickraja *et al.* (2024) in direct dry-seeded rice. The results of the current study are in agreement with earlier findings that pre-emergence herbicides serve as the principal tool and foundation of the most effective weed management programs in cotton.

Cotton, yield attributes, yield

Implementing weed management measures led to better growth and yield attributes compared to the un-weeded control. Application of UAV spray using spray volume of 37.5 L/ha resulted in increased plant

Table 1. Effect of weed management treatments on weed density, weed biomass and weed control efficiency (WCE) at 80 DAS in summer cotton

Treatment	Volunteer rice	*E. colona*	Other grasses	*C. iria*	*C. viscosa*	Other BLW	Total weeds	WCE
Weed density (no./m^2)								
Pendimethalin 1.0 kg/ha PE using knapsack sprayer - spray volume of 500 L/ha	1.96(3.3)	7.56(56.7)	0.71(0.0)	2.68(6.7)	3.44(11.3)	1.96(3.3)	9.05(81.3)	92.8
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 25 L/ha	2.55(6.0)	8.40(70.0)	0.71(0.0)	2.92(8.0)	3.63(12.7)	2.27(4.7)	10.1(102.0)	89.8
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 37.5 L/ha	1.58(2.0)	6.52(42.0)	0.71(0.0)	2.27(4.7)	3.03(8.7)	0.71(0.0)	7.65(58.0)	95.9
Pendimethalin 1.0 kg/ha PE using drone- spray volume of 50 L/ha	2.12(4.0)	7.11(50.0)	0.71(0.0)	2.68(6.7)	3.24(10.0)	1.08(0.7)	8.55(72.7)	93.5
Inter-cultivation twice at 20 and 45 DAS	2.27(4.7)	8.63(74.0)	0.71(0.0)	2.42(5.3)	3.14(9.3)	2.68(6.7)	10.2(104.0)	90.3
Inter-cultivation twice + manual weeding at 60 DAS	1.35(1.3)	6.72(44.7)	0.71(0.0)	2.27(4.7)	3.03(8.7)	0.71(0.0)	7.82(60.7)	95.7
Un-weeded control	2.42(5.3)	16.7(279.3)	7.69(58.7)	5.58(30.7)	7.47(55.3)	7.52(56.0)	22.0(483.3)	-
LSD (p=0.05)	0.6	1.7	0.1	0.4	0.4	0.6	1.3	
Weed biomass (g/m^2)								
Pendimethalin 1.0 kg/ha PE using knapsack sprayer - spray volume of 500 L/ha	2.51(5.8)	4.39(18.7)	0.71(0.0)	1.65(2.2)	2.50(5.7)	1.81(2.8)	5.89(34.2)	
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 25 L/ha	3.14(9.4)	4.84(22.9)	0.71(0.0)	1.96(3.3)	2.75(7.1)	2.51(5.8)	7.00(48.5)	
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 37.5 L/ha	1.47(1.6)	3.86(14.4)	0.71(0.0)	1.33(1.3)	1.65(2.2)	0.71(0.0)	4.47(19.5)	
Pendimethalin 1.0 kg/ha PE using drone- spray volume of 50 L/ha	2.30(4.8)	4.24(17.5)	0.71(0.0)	1.57(2.0)	2.26(4.6)	1.09(0.7)	5.58(30.7)	
Inter-cultivation twice at 20 and 45 DAS	2.68(6.7)	5.22(26.8)	0.71(0.0)	1.98(3.4)	1.95(3.3)	2.55(6.0)	6.83(46.2)	
Inter-cultivation twice + manual weeding at 60 DAS	1.29(1.2)	3.95(15.1)	0.71(0.0)	1.40(1.4)	1.72(2.5)	0.72(0.0)	4.55(20.2)	
Un-weeded control	2.07(3.8)	18.4(339.4)	6.73(44.8)	4.33(18.2)	4.28(17.9)	7.11(50.0)	21.8(474.1)	
LSD (p=0.05)	0.1	0.4	0.1	0.1	0.1	0.3	0.4	

* Data in parentheses are original values; Data were subjected to square root transformation ($\sqrt{x+0.5}$); DAS = days after seeding; PE = pre-emergence application; BLW = broad-leaved weeds; *E. colona*: *Echinochloa colona; C. iria: Cyperus iria; C. viscosa: Cleome viscosa*

Table 2. Effect of weed management treatments on growth, yield and weed index in summer cotton

Treatment	Plant height (cm)	No. of bolls/ plant	Boll weight (g)	Seed cotton yield (kg/ha)	Weed index
Pendimethalin 1.0 kg/ha PE using knapsack sprayer - spray volume of 500 L/ha	160.5	56.4	4.4	3735.9	10.9
Pendimethalin 1.0 kg/ha PE using drone -spray volume of 25 L/ha	154.9	51.7	4.1	3516.8	16.1
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 37.5 L/ha	184.3	63.6	4.6	4193.9	-
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 50 L/ha	176.6	62.1	4.5	4076.5	2.8
Inter-cultivation twice at 20 and 45 DAS	140.6	46.7	4.0	3053.4	27.2
Inter-cultivation twice + manual weeding at 60 DAS	158.1	49.5	4.4	3300.7	21.3
Un-weeded control	90.1	11.7	3.2	515.2	87.7
LSD (p=0.05)	4.1	3.4	0.3	362.3	

*DAS = days after seeding; PE = pre-emergence application

Table 3. Effect of various weed management treatments on economics of summer cotton

Treatment	General cost of cultivation including harvesting (x10^3 Rs./ha)	Weed management cost (x10^3 Rs./ha)	Total cost of cultivation (x10^3 Rs./ha)	Gross returns (x10^3 Rs./ha)	Net returns (x10^3 Rs./ha)	B:C ratio
Pendimethalin 1.0 kg/ha PE using knapsack sprayer – spray volume of 500 L/ha	84.74	3.38	88.12	242.83	15.47	2.75
Pendimethalin 1.0 kg/ha PE using drone -spray volume of 25 L/ha	81.14	2.68	83.82	228.59	14.48	2.73
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 37.5 L/ha	90.74	2.68	93.42	272.60	17.92	2.90
Pendimethalin 1.0 kg/ha PE using drone - spray volume of 50 L/ha	89.14	2.68	91.82	264.97	17.31	2.88
Intercultivation twice at 20 and 45 DAS	71.84	7.50	79.34	198.47	11.91	2.50
Intercultivation twice + manual weeding at 60 DAS	75.04	13.50	88.54	214.55	12.60	2.42
Unweeded control	37.84	-	37.84	33.47	-4.4	0.88

Statistically not analysed; DAS = days after seeding; PE = pre-emergence application

height by 51.1% compared to the un-weeded control. The efficient suppression of weed growth in 37.5 L/ ha, enhanced nutrient absorption, higher interception of sunlight resulting in greater resource allocation of photosynthates to the yield-attributes and increased 81.6 and 34.7% higher boll numbers and boll weight, respectively compared to the un-weeded control (**Table 2**). Application of UAV spray at 37.5 L/ha recorded higher seed cotton yield due lower weed density, biomass and higher weed control efficiency. However, when weeds were left uncontrolled throughout the growing season induced stress on cotton by competing for resources and hindering overall cotton growth and reducing cotton yield by 87.7%

The scatter plot reveals a strong negative correlation (R^2 = 0.88) between seed cotton yield and weed biomass, indicating that in increase in weed biomass by 1.0 g significant decrease in seed cotton yield by 13.5 kg/ha (**Figure 2)**. Singh *et al*. (2022) reported cotton yield losses of 50 to 85% due to uncontrolled weeds in cotton.

Economics

Application of pendimethalin 1.0 kg/ha PE using drone-spray volume of 37.5 L/ha resulted in the higher gross, net return and B: C ratio of 2.90 **(Table 3)**. The lowest B: C ratio (0.88) and net return were observed in un-weeded control because of poor seed cotton yield. In general, the cost of weed management was lower with pendimethalin 1.0 kg/ha PE using all drone-spray volume plots (₹ 2679/ha) compared to either inter-cultivation twice *fb* manual weeding plot (₹ 13500/ha) or application of pendimethalin 1.0 kg/ha PE using with knapsack sprayer (₹ 3379/ha). Garre and Harish (2018) opined that using drones to apply plant protection chemicals could reduce production costs.

Thus, it was concluded that farmers can opt for pre-emergence application of pendimethalin 1.0 kg/ha 3 DAS using UAV spray with a spray volume of 37.5 L/ha to effectively manage the diverse weed flora and enhance the summer cotton yield.

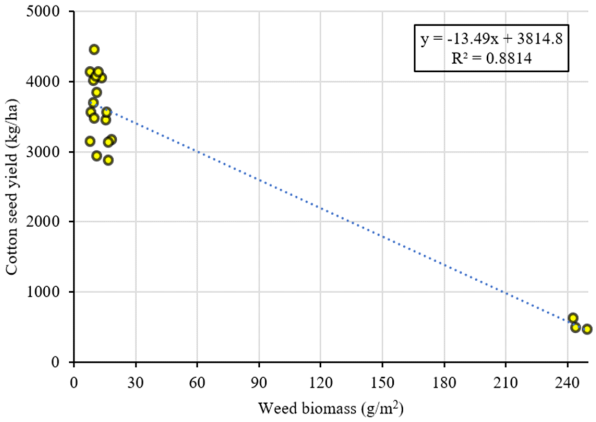

Figure 2. Relationship between weed biomass and seed cotton yield at harvest stage in summer cotton

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