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Optimizing the Application Time of Pre-emergence Herbicide Pendimethalin and Oxyfluorfen Application for Effective Weed Management in Irrigated Blackgram (*Vigna mungo* L.) and Its Residue Persistence

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ABSTRACT

Background: Time of pre-emergence herbicide application is an important factor that decides the efficiency of herbicide. If the pre-emergence herbicide is not applied at appropriate time, it may cause ineffective weed control or toxicity to crops. With this background, a field experiment was conducted at TNAU, Madurai to optimize the time of pre-emergence herbicides namely pendimethalin and oxyfluorfen application for effective weed management in irrigated blackgram.

Methods: The experiment was laid out in randomized block design with three replication. Treatments were application of pendimethalin at 0.75 kg ha^{-1} and oxyfluorfen at 0.2 kg ha^{-1} on 1, 2, 3, 4 days after sowing, weed free check and unweeded check.

Result: Results of the study revealed that oxyfluorfen gave maximum weed control efficiency as compared to pendimethalin, but toxicity to the crop was observed when oxyfluorfen was sprayed after 2 days of sowing. Yield and economics were achieved higher with application of 0.75 kg ha^{-1} of pendimethalin at 2 DAS, which was on par with application of 0.2 kg ha^{-1} of oxyfluorfen at 1 DAS due to lesser toxicity. Application of 0.75 kg ha^{-1} of pendimethalin and 0.2 kg ha^{-1} of oxyfluorfen didn't leave any herbicide residue after harvest. Hence, application of 0.75 kg ha^{-1} of pendimethalin at 2 DAS and 0.2 kg ha^{-1} of oxyfluorfen at 1 DAS can be recommended for effective weed management in irrigated balckgram.

Key words: Application time, Blackgram, Oxyfluorfen, Pendimethlain, Residue persistence.

INTRODUCTION

In Indian diet, pulses are the important constituent of protein supplement. In addition to the rich source of protein, it also fix the atmospheric nitrogen in the soil, thereby it maintains soil fertility. Pulses can be very well fitted with mixed/ intercropping cropping and crop rotation, so most of the time, it will be the integral part of the cropping system. India is one of the largest producer and consumer of pulses and it occupies about 33.6 per cent of the world's pulses production area and 24 per cent of the world's pulse production (Pramanik and Bera, 2012). Among the pulse crop, blackgram (*Vigna mungo* L.) is an important legume crop cultivated worldwide in tropical and subtropical regions.

In India, it occupies an area of 3.06 million hectares with a production of 1.70 million tones and average productivity is only 555 kg ha^{-1}. In Tamil Nadu, blackgram is cultivated in 365.1 lakh hectares, with the productivity of 751 kg ha^{-1} (India stat, 2019). Even though various factors accountable for the lower yield of blackgram, weeds are considered to be the prime factor that causes exorbitant yield losses. Reduction in yield may be as high as 30-50% or even more depending upon the intensity of weeds and type of weed flora (Rao *et al*., 2010).

Conventional hand weeding is highly costlier, increasing demand for agricultural labour due to migration of labours from the rural to urban areas, again it affects the timeliness in weeding. The next best alternate is chemical weed management. Pendimethalin and Oxyfluorfen were the important pre emergence herbicide. Pendimethalin is one of the several members of the class of dinitroaniline herbicides, which has been officially recommended in India as soil-applied pre-emergence herbicides and it has selective weed control properties. It affects hill reaction of weeds. Oxyfluorfen is a diphenyl-ether herbicide used for broad-spectrum pre- and post-emergent to control of annual

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broadleaf and grassy weeds in a variety of field crops by affecting the spindle fiber formation (Priya *et al.,* 2017).

Pre-emergence herbicides, generally practiced for weed management in pulse crop, should be applied at appropriate time to get maximum weed control efficiency because pulses are more sensitive to herbicide, if not apply in time may cause herbicidal toxicity to plants or ineffective to manage the weed. Literature related to efficiency of these herbicides at different dose for different crops are available adequately. However, information related to optimum time of herbicide application for achieving maximum weed control efficiency is lacking.

Oxyfluorfen is persistent and relatively immobile in soil. Oxyfluorfen can contaminate surface water through spray drift and runoff and long persistence can also affect succeeding crop (Singh *et al*., 2014), this emphasizes the importance of residue persistence and degradation study.

By having this idea in background the present study was carried out to optimize the time of herbicide application to achieve effective weed control and its persistence.

MATERIALS AND METHODS

Details of the experimental site

A field experiment was conducted at Agricultural College and Research institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India to optimize the application time of pre emergence herbicide pendimethalin and oxyfluorfen for effective weed management in irrigated blackgram and also to study the herbicide persistence and degradation during summer 2018. The experimental site is located at 9°54′ N latitude and 78°54′ E longitude at an altitude of 147 m above MSL. The mean maximum and minimum temperature are 33.35°C and 20.35°C, respectively. The rainfall received during cropping season was 86.8 mm in 15 rainy days. The mean relative humidity ranges from 49 to 70 percent. The soil texture was sandy clay loam. The soil was near neutral pH and low in available nitrogen. The initial soil sample analysis results were furnished below (Table 1).

Table 1: Soil properties.

Parameters		Analysed values
I Mechanical properties		
Clay (%)	:	22.45
Slit (%)	:	11.35
Sand (%)	:	66.2
Textural Class	:	Sandy clay loam
Bulk density (g cc^{-1})	:	1.33
II Chemical properties		
pH	:	7.47
EC (dS m^{-1})	:	0.43
Available N (kg ha^{-1})	:	240.51
Available P (kg ha^{-1})	:	16.37
Available K (kg ha^{-1})	:	290.63
Organic carbon (%)	:	0.49

Experimental details

The experiment was laid out in randomized block design comprised of ten treatments and three replications. Pendimethalin at 0.75 kg ha^{-1} and oxyfluorfen at 0.2 kg ha^{-1} were applied as pre-emergence at 1, 2, 3, 4 days after sowing; weed free check and unweeded check also included in this experimental plots to compare with herbicide application over standard check. The crop was sown on 16.02.2017 and harvested on 27.04.2017. Pendimethalin was purchased from Rallis India with the commercial name of Penida (30% EC) and Oxyfluorfen was purchased from Dow Agro Science with the commercial name of Goal (23.5% EC). Blackgram variety MDU1 was used for the study and its characters were furnished in Table 2.

Observations recorded

Weed population

The weed species in each plot were counted at four randomly selected spots using a quadrate (0.25 m^2) at 20 and 50 days after sowing. Then the weeds were grouped into grasses, sedges, broad leaved weeds, those values were expressed as number m^{-2}. Weed dry weight was recorded at 20 and 50 days after sowing. Weeds found within the four (0.25 m^2) quadrate outside the net plot area in each plot were pulled out, sun dried and oven dried at 65°C ± 5°C until it reached a constant weight. The dry matter of weed was expressed in kg ha^{-1}. Weed control efficiency was worked out based on Mani *et al*., (1973) method and Weed index was calculated based on the procedure suggested by Gill and Vijayakumar, (1969).

Plant observations

Biometric observations like plant height, dry matter production and yield parameters like number of pods per plant, number of seeds per pod, 100 seed weight, grain and haulm yield of black gram were recorded. The data on different parameters were analyzed statistically by adopting Fisher’s method of ANOVA suggested by Gomez and Gomez (1984).

Herbicide residue analysis

Soil samples were collected at 24 hours interval *viz.*, 0 (2 hrs) - 30 days after herbicide application and also at the time of crop harvest. About 2 kg of soil sample was collected randomly from each plot using a soil auger up to a depth of 5 cm from the surface. Pebbles and other unwanted materials were removed, the soil sample was homogenized thoroughly and about 250 g was sub sampled for the analysis of herbicide residues. Residues were analysed by using GCMS-QP2020 model. Regression analysis was done for determining half-life of the herbicide.

RESULTS AND DISCUSSION

Effect of time of pendimethalin and oxyfluorfen application on weeds

Weed density and total dry weight

The data on grass, broad leaved weeds and sedges density as well as total dry weight were recorded on 20

Table 2: Characteristics of blackgram MDU 1.

Character	Description
Special Features:	Good batter quality (Arabinose 7.5%, Globulin 12.1%)
100 grain weight	5.2 g
Resistance to and disease	Moderately resistant to YMV pest and pod borer and Resistant to leaf crinkle virus
Suitable season	*Rabi*
Parentage:	ADB 2003 X VBG 66
Duration :	70 -75 days
Source of release	Agricultural College and Research Institute, Madurai.
Yield potential	1.42 tonnes ha-1

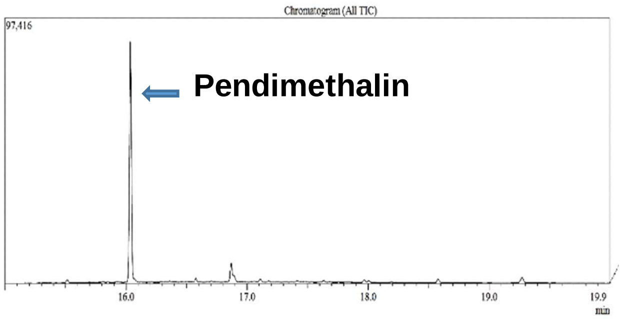

Fig 1a: Chromatogram for pendimethalin detection.

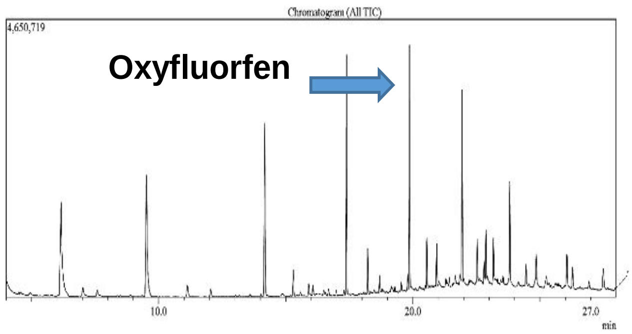

Fig 1b: Chromatogram for oxyfluorfen detection.

days after sowing (DAS) and 50 DAS and that were presented in Table 3.

Population of grasses, sedges and broad leaved weeds as well as dry weight of the weeds were significantly influenced by time of application of pre emergence herbicides pendimethalin and oxyfluorfen. Among the application of herbicides at different days interval, oxyfluorfen applied at 0.20 kg ha^{-1} on 1 DAS recorded lower weed density of grasses (31.00 and 68.67 Number m^{-2}, respectively on 20 and 50 DAS), sedges (42.67 and 79.24 Number m^{-2}, respectively on 20 and 50 DAS) and broad leaved weeds (6.33 and 56.35 Number m^{-2}, respectively on 20 and 50 DAS). It was on par with application of oxyfluorfen at 0.20 kg ha^{-1} on 2 DAS and pendimethalin at 0.75 kg ha^{-1} on 2 DAS except with sedge population. Higher weed density and dry weight were observed with pendimethalin application at 0.75 kg ha^{-1} on 4 DAS (Table 3). It was mainly due to ineffective weed control (Mansoori *et al*., 2015). Application of oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS recorded 5.05 and 3.91 times reduced weed dry weight, respectively on 20 and 50 DAS compared to weedy check. It was comparable with application of oxyfluorfen at 0.20 kg ha^{-1} on 2 DAS and pendimethalin at 0.75 kg ha^{-1} on 2 DAS. Lower weed dry weight was mainly due to reduction in weed density.

Weed control efficiency and weed index

Among the application of herbicides at different days interval, higher weed controlling efficiency of 83.93 and 76.70 per cent respectively during 20 and 50 DAS were obtained from oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS followed by application of oxyfluorfen at 0.20 kg ha^{-1} on 2 DAS. However, lower weed controlling efficiency was achieved with application of pendimethalin at 0.75 kg ha^{-1} on 4 DAS (Table 3). Maximum WCE obtained by the above promising weed management practices was due to the greater reduction of dry matter accumulation of different weed species (Rao *et al*., 2010). While the weed index was lower with application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS, which was followed by oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS (Table 3). It was mainly due to increased grain yield (Sheikh *et al*., 2010).

Effect of time of application on plant biometric observations

Plant growth attributes

The growth characters of a plant are manifested in many ways. Plant height, leaf area and dry matter production (DMP) are the important growth characters. The source-sink relationship mainly depends on these important growth parameters. Even though oxyfluorfen recorded better results with weed control, later application after 3 days of sowing produced considerable toxicity to the crop (Fig 2). It might be due to direct contact of herbicide with germinating plant parts during spraying. So it negatively influenced the growth attributes of blackgram.

Among the application of herbicide at different days interval, application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS (38.2 cm) recorded higher plant height, which was comparable application of oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS (Table. 4a). Dry matter production and LAI were also higher with application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS, which was at par with the application of oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS. Lower plant growth parameters were observed with application of oxyfluorfen at 0.20 kg ha^{-1} on 4 DAS (Table. 4a). It was mainly due to toxicity of herbicide when it was applied after 2 days of sowing (Fig 2).

Yield attributes and yield

Among the application of herbicide at different days interval, the higher yield attributes *viz*, pods plant^{-1} (35.9), number of seed pod^{-1} (8.6) were higher with application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS. It was comparable with application of oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS. This was mainly due to improved growth attributing

Table 3: Effect of time of application of pendimethalin and oxyfluorfen on weed density, total weed dry weight, weed control efficiency, weed index in blackgram.

T. No	Treatments	Grasses (No.m^{-2})		Sedges (No.m^{-2})		Broad leaved weeds (No.m^{-2})		Weed dry weight (kg ha^{-1})		WCE (%)		Weed Index
		20 DAS	50 DAS	20 DAS	50 DAS	20 DAS	50 DAS	20 DAS	50 DAS	20 DAS	50 DAS	Harvest stage
T_1	Pendimethalin at 0.75 kg on 1 DAS	38.67 (6.26)	86.74 (9.34)	68.76 (8.32)	136.39 (11.70)	18.00 (4.30)	103.34 (10.19)	110.60 (10.54)	2472.47 (49.73)	72.55	61.63	54.64
T_2	Pendimethalin at 0.75 kg on 2 DAS	37.00 (6.12)	70.73 (8.44)	47.32 (6.92)	108.08 (10.42)	8.70 (3.03)	61.59 (7.88)	79.79 (8.96)	1805.83 (42.50)	80.19	72.25	4.74
T_3	Pendimethalin at 0.75 kg on 3 DAS	67.331 (8.24)	14.42 (10.72)	84.00 (9.19)	177.99 (13.36)	16.70 (4.15)	158.26 (12.60)	183.73 (13.57)	3452.11 (58.76)	54.39	46.58	20.10
T_4	Pendimethalin at 0.75 kg on 4 DAS	82.00 (9.08)	120.06 (10.98)	86.29 (9.32)	200.29 (14.17)	24.67 (5.02)	194.10 (13.95)	207.41 (14.42)	3945.74 (62.82)	48.52	38.38	32.58
T_5	Oxyfluorfen at 0.2 kg on 1 DAS	31.00 (6.36)	68.72 (8.32)	42.67 (6.57)	79.24 (8.93)	6.33 (2.61)	56.35 (7.54)	64.74 (8.08)	1555.30 (39.44)	83.93	76.70	5.67
T_6	Oxyfluorfen at 0.2 kg on 2 DAS	33.67 (6.62)	76.41 (8.77)	49.00 (7.04)	96.24 (9.86)	10.00 (3.24)	60.03 (7.78)	70.43 (8.42)	1759.75 (41.96)	82.52	73.40	10.62
T_7	Oxyfluorfen at 0.2 kg on 3 DAS	68.00 (8.28)	76.06 (8.75)	75.32 (8.71)	126.29 (11.26)	12.33 (3.58)	63.98 (8.03)	115.79 (11.12)	1992.83 (44.65)	71.26	69.23	56.70
T_8	Oxyfluorfen at 0.2 kg on 4 DAS	77.00 (8.97)	79.96 (8.97)	80.69 (9.01)	134.06 (11.60)	20.00 (4.53)	90.32 (9.53)	152.60 (12.37)	2298.69 (47.95)	62.12	64.29	58.45
T_9	Weed free check	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	100.00	100.00	0.00
T_{10}	Unweeded control	270.10 (16.89)	402.30 (20.07)	108.36 (10.43)	207.10 (16.45)	152.33 (12.36)	240.06 (15.51)	402.86 (20.08)	7054.13 (83.99)	0.00	0.00	60.82
	SEd	0.30	0.40	0.23	0.41	0.31	0.46	0.44	1.73	-**	-**	-**
	CD(P= 0.05)	0.63	0.83	0.49	0.86	0.63	0.96	0.92	3.64	-**	-**	-**

*DAS- Days after sowing, Data were subjected to "(X + 0.5) transformation, Figures in parenthesis are the means of transformed data.

**Data were not statistically analysed.

characters (Raman *et al*., 2005). Test weight of the seeds didn't exhibit significant variation among the treatments (Table 4b), because it is the genetic character of the variety.

Higher grain yield of 924 kg ha^{-1} (Table 4b) was observed with application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS. Rathi *et al*., 2004, also found that weed management by using pendimethalin herbicide at the rate of 0.75 kg ha^{-1} recorded higher yield. It was at par with application oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS (Table 4b). It was mainly due to improved growth and yield attributing characters due to effective weed management (Singh, 2011). The lower grain and straw yield were observed with application oxyfluorfen at 0.20 kg ha^{-1} on 4 DAS and unweeded control. Higher straw yield of 1704 kg ha^{-1} was recorded with application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS and oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS (Table 4b). It was mainly due to effective weed control that improved nutrient availability and ultimately increased the biomass of black gram. Harvesting index was higher with application of oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS (Table 4b).

Economics

Higher crop productivity with lesser cost of cultivation could result in better economic parameter like net returns and B: C ratio (Table 5). Even though weed free check recorded higher yield and higher gross return, cost of cultivation was very high due to periodical manual weeding. Nandal and Ravinder Singh, (2002) also found that application of pendimethalin at 0.75 kg ha^{-1} and oxyfluorfen at 0.2 kg ha^{-1} were recorded lesser cost of cultivation and higher B:C ratio compared to manual weeding. Higher net return was recorded with application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS, it was followed by application of oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS. Higher B:C ratio of 2.95 was observed with application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS, it was followed by application of oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS with negligible variation (Table 5). It was mainly due to reduced input cost and increased output (Agila and Chinnamuthu, 2018).

Herbicide residue study

The correlation coefficient (R^2) derived from the regression lines lies between 0.96 and 0.85 (Table 6a) and the best fit was observed for pendimethalin in which dissipation followed biphasic pattern of degradation *i.e.* initial faster dissipation up to 10 days thereafter the dissipation becomes slow.

Table 4a: Effect of time of application of pre-emergence herbicides pendimethalin and oxyfluorfen on biometric observations and LAI.

T. No	Treatments	Plant height (cm)	Dry matter production (kg ha^{-1})	LAI (50 DAS)
T_1	Pendimethalin at 0.75 kg on 1 DAS	31.7	1576	3.97
T_2	Pendimethalin at 0.75 kg on 2 DAS	38.2	2764	4.92
T_3	Pendimethalin at 0.75 kg on 3 DAS	33.6	2467	4.68
T_4	Pendimethalin at 0.75 kg on 4 DAS	32.1	2321	4.13
T_5	Oxyfluorfen at 0.2 kg on 1 DAS	37.0	2713	4.83
T_6	Oxyfluorfen at 0.2 kg on 2 DAS	29.3	2485	4.39
T_7	Oxyfluorfen at 0.2 kg on 3 DAS	27.4	1535	3.77
T_8	Oxyfluorfen at 0.2 kg on 4 DAS	25.7	1500	3.46
T_9	Weed free check	41.0	2900	4.97
T_{10}	Unweeded control	30.3	1502	3.24
	SEd	1.627	121.00	0.2745
	CD(P = 0.05)	3.419	254.21	0.5766

Table 4b: Effect of time of application of pre-emergence herbicides pendimethalin and oxyfluorfen on yield parameters and yield in blackgram.

T. No	Treatments	No. of pods $plant^{-1}$	No. of seeds pod^{-1}	Test weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvesting index
T_1	Pendimethalin at 0.75 kg on 1 DAS	23.0	6.7	5.4	440	1121	27.8
T_2	Pendimethalin at 0.75 kg on 2 DAS	33.8	7.9	5.7	924	1704	39.1
T_3	Pendimethalin at 0.75 kg on 3 DAS	27.6	7.2	5.6	775	1456	37.1
T_4	Pendimethalin at 0.75 kg on 4 DAS	24.9	6.9	5.5	654	1523	35.5
T_5	Oxyfluorfen at 0.2 kg on 1 DAS	31.5	7.8	5.7	915	1687	39.8
T_6	Oxyfluorfen at 0.2 kg on 2 DAS	28.9	7.5	5.6	867	1531	36.6
T_7	Oxyfluorfen at 0.2 kg on 3 DAS	22.7	6.6	5.4	420	1100	34.8
T_8	Oxyfluorfen at 0.2 kg on 4 DAS	21.6	6.4	5.3	403	1078	37.0
T_9	Weed free check	35.9	8.6	5.7	970	1887	39.1
T_{10}	Unweeded control	20.2	6.1	5.2	380	1083	27.5
	SEd	1.316	0.328	0.350	24.99	106.74	2.329
	CD(P = 0.05)	2.765	0.688	NS	52.50	224.25	4.893

*DAS- Days after sowing.

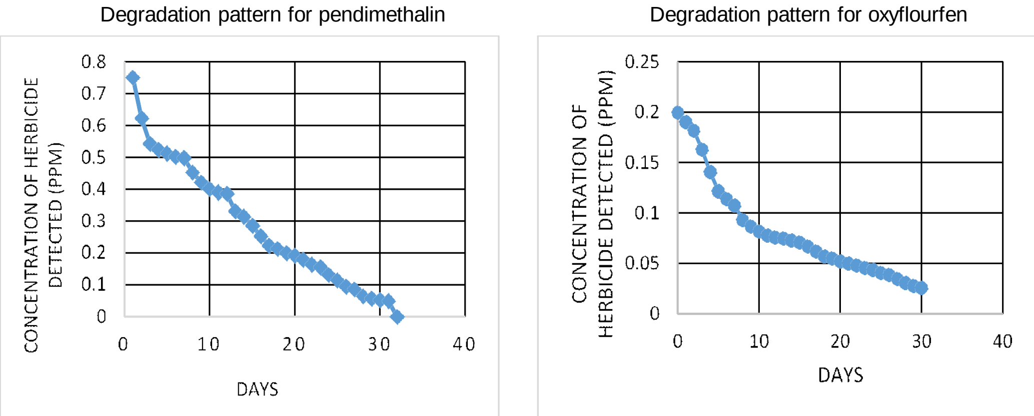

Fig 3: Degradation pattern of pendimethalin and oxyflourfen under field conditions.

Table 5: Effect of time of application of pre-emergence herbicides pendimethalin and oxyfluorfen on economics.

T. No	Treatments	Rs.ha^{-1}			
		Cost of cultivation	Gross Return	Net return	B:C Ratio
T_1	Pendimethalin at 0.75 kg on 1 DAS	17245	24200	6955	1.40
T_2	Pendimethalin at 0.75 kg on 2 DAS	17245	50820	33575	2.95
T_3	Pendimethalin at 0.75 kg on 3 DAS	17245	42625	25380	2.47
T_4	Pendimethalin at 0.75 kg on 4 DAS	17245	35970	18725	2.09
T_5	Oxyfluorfen at 0.2 kg on 1 DAS	17096	50325	33229	2.94
T_6	Oxyfluorfen at 0.2 kg on 2 DAS	17096	47685	30589	2.79
T_7	Oxyfluorfen at 0.2 kg on 3 DAS	17096	23100	6004	1.35
T_8	Oxyfluorfen at 0.2 kg on 4 DAS	17096	22165	5069	1.30
T_9	Weedy check	28735	53350	24615	1.86
T_{10}	Unweeded control	14821	20900	6079	1.41

*Data not statistically not analysed.

Table 6a: Gas chromatography Mass Spectrometer analysis details of pendimethalin and oxyfluorfen.

Herbicides applied	Retention time (minutes)	Limit of detection (µg/g)	Average recovery from soil
Pendimethalin	16.055	0.001	86%
Oxyfluorfen	19.770	0.001	89%

Table 6b: Half-life period of pendimethalin and oxyfluorfen herbicide in soil.

Herbicides	Half-life (Days)	Predicted equation	Goodness of fit
Pendimathalin	12.47	$y = -0.0205x + 0.6037$	$R^2 = 0.9603$
Oxyfluorfen	11.36	$y = -0.0052x + 0.1591$	$R^2 = 0.8481$

Efficiency of the extraction methods for both the herbicides were validated through recovery studies and found that the overall recovery of the herbicides were 86 per cent for pendimethalin and 89 per cent for oxyfluorfen (Table 6a). It confirmed the suitability of the extraction methods for the determination of pendimethalin and oxyfluorfen residues in soil.

The initial concentration (2 hours after application) of both the herbicides in soil was varied with the quantity of application (pendimethalin at 0.75 kg ha^{-1} and oxyfluorfen at 0.20 kg ha^{-1}). Generally higher rate of degradation was recorded during the initial period of observation for both the herbicide (Fig 3).

The half-life period of pendimethalin and oxyfluorfen was influenced by its chemical properties. The mean half-life of initial concentration of herbicides studied in sandy clay loam was 12.47 and 11.36 days for pendimethalin and oxyfluorfen, respectively (Table 6b).

Thirty days after application, the persistence of pendimthalin (0.75 kg ha^{-1}) and oxyfluorfen (0.20 kg ha^{-1}) in soil was registered as 0.049 and 0.026 kg ha^{-1}, respectively. Among the two herbicides studied, pendimethalin dissipated at a faster rate compared to oxyfluorfen (Arora and Tomar, 2008). None of the herbicides were persistent in soil after the harvest of blackgram (Naidu *et al*., 2012 and Priya *et al*., 2017). These applied dose of herbicide won't harm the succeeding crop and safer for the environment.

CONCLUSION

Time of herbicide application plays an important role in effective weed management. Compared to pendimethalin, oxyfluorfen application produced higher weed controlling efficiency but application of oxyfluorfen at later stage after 3 days of sowing recorded higher toxicity to germinating crop.

Application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS recorded higher biomass, yield and economic return compare to other herbicidal treatments. Application of oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS recorded lesser toxicity compared to other oxyfluorfen treatments and produced comparable results with application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS. Residue leftover was also not available after harvest of the crop. So it will not affect the succeeding crop. Ultimately, it can be recommended as application of pendimethalin at 0.75 kg ha^{-1} on 2 DAS and application of oxyfluorfen at 0.20 kg ha^{-1} on 1 DAS are the best suitable time of herbicide application for getting maximum weed controlling efficiency, more yield and economic return.

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