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Bio-efficacy of pre and post-emergent herbicides with or without inter-cultivation on sunflower (*Helianthus annuus* L.) in Northern transition tract of Karnataka

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Abstract
A field experiment was replicated thrice in randomised complete block design on vertisols at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad during late *kharif* 2018 to study the bio-efficacy of pre and post-emergent herbicides with or without inter-cultivation (IC) on sunflower. Significantly higher seed yield (q ha^{-1}), weed control efficiency at 60 DAS (%) and net returns (₹ ha^{-1}) recorded with the application of Pendimethalin 38.7 CS @ 750 g a.i. ha^{-1} - PE *fb* IC at 35 DAS (20.7, 93.62 and 43074, respectively) compared to Farmers practice (19.5, 91.43 and 34193, respectively). However, it was on par with Pendimethalin 30 EC @ 1000 g a.i. ha^{-1} - PE *fb* IC at 35 DAS, Sulfentrazone 48 SC @ 192 g a.i. ha^{-1} - PE *fb* IC at 35 DAS, Quizalofop-p-ethyl 5 EC @ 75 g a.i. ha^{-1} - POE *fb* IC at 35 DAS, Propaquizafop 10 EC @ 75 g a.i. ha^{-1} - POE *fb* IC at 35 DAS and Fenoxaprop-p-ethyl 9.3 EC @ 50 g a.i. ha^{-1} - POE *fb* IC at 35 DAS.

Keywords: Sunflower, pendimethalin, inter-cultivation, weed control efficiency

Introduction
Sunflower (*Helianthus annuus* L.) is an annual oilseed crop belongs to family *Asteraceae* and popularly known as "*Surajmukhi*" or "*Sooryakanthi*". It contains 35-45 per cent of oil. Sunflower oil is considered as premium due to its rich source of linoleic acid (64%) which reduces low density lipid blood cholesterol in humans, hence, recommended to heart patients. Sunflower can be cultivated throughout the year due to its photo- and thermo-insensitivity character. In Karnataka, sunflower crop covers an area of 220,000 hectares with 98,000 tonnes of production and the productivity is 455 kg ha^{-1} (Anon., 2017) [1]. In the state, major sunflower acreage (85%) is confined to Vijayapur, Bellary, Kalaburgi, Raichur, Dharwad and Chikkaballapur districts.

Sunflower has wider spacing and demand more quantity of fertilizer which made weeds to grow abundantly in rows by exploiting the nutrients and moisture and supress the growth of the crop. So, sunflower is highly subjected to weed competition. Initial four weeks of crop is the most critical in detecting harmful effects of weeds competition. During *kharif* and spring about 45 days and 30-45 days of weed free conditions needed in sunflower to get higher yields, respectively (Wanjari *et al.*, 2000) [8]. In sunflower, yield loss caused by weeds is about 81 per cent (Jayakumar *et al.*, 1988) [5]. So, it is necessary to control weeds timely to optimize the sunflower yield. In order to manage weeds during critical period of crop-weed competition there is a need to evaluate the best weed management practices. The development of pre- and post-emergent herbicides in addition with inter-cultivation provide solutions for efficient management of crop, thereby opening enormous possibilities of increasing the sunflower productivity.

Material and Methods
A field experiment was conducted at Main Agricultural Research Station (15° 29′ 45″ N | 74° 59′ 19″ E | 700 m MSL), University of Agricultural Sciences, Dharwad [Northern Transition Zone (Zone 8)], Karnataka on medium black clay soil (pH of 7.64) with medium in available nitrogen (308.42 kg N ha^{-1}), high in available phosphorus (28.64 kg P_2O_5 ha^{-1}) and potassium (345.14 kg K_2O ha^{-1}) during late *kharif* 2018. The experiment was replicated thrice in Randomized Complete Block Design (RCBD) with 15 treatments. The study included, three pre-emergent (PE) herbicides (Pendimethalin 30 EC, Pendimethalin 38.7 CS, Sulfentrazone 48 SC) and three post-emergent (POE) herbicides (Propaquizafop 10 EC, Quizalofop-p-ethyl 5

EC, Fenoxaprop-p-ethyl 9.3 EC) with and without inter-cultivation (IC) at 35 days after sowing (DAS) and Farmers practice (two hand weeding at 15 and 30 DAS + one IC at 40 DAS). Sunflower hybrid DSFH-3 was selected for the study with the normal spacing 60 x 30 cm. Farm yard manure @ 7 t ha^{-1} was applied at two weeks before planting. The nutrients nitrogen, phosphorus and potassium were applied as per the recommended dose of 35:50:35 N, P_2O_5 and K_2O kg ha^{-1} through fertilizers urea, DAP and MOP. The 50 per cent of nitrogen and entire dose of phosphorus and potassium were applied as basal and remaining 50 per cent nitrogen applied at 35 DAS. Pre-emergent herbicides were applied one day after sowing and post-emergent herbicides were applied at 2-3 leaf stage of weeds (20 DAS). Weed density, weed dry weight, weed control efficiency were recorded at 60 DAS. Yield and yield parameters of sunflower were recorded at the time of harvest. The weed control efficiency (WCE) and weed index (WI) were calculated by using the following formulae.

$$WCE\ (\%) = \frac{X - Y}{X} \times 100$$

Where, WCE = Weed Control Efficiency, expressed in percentage, X = Total weed dry weight in unweeded control plot, Y = Total weed dry weight in the treated plot

$$WI\ (\%) = \frac{X - Y}{X} \times 100$$

Where, WI = Weed Index expressed in percentage, X = Yield of weed free plot, Y = Yield from treatment for which weed index is to be worked out

Results and Discussion

The predominant weed flora present in the experimental site consists of grasses, sedges and broad-leaved weeds. Among the grasses, *Cynodon dactylon*, *Dinebra retroflexa*, among sedges, *Cyperus rotundus* and among broad-leaves weeds, *Digera arvensis*, *Parthenium hysterophorus*, *Commelina benghalensis*, *Phyllanthus maderaspatensis*, *Corchorus olitorius* were the major weeds found in the experimental area. Similar weed spectrum associated with sunflower crop was also observed by Suresh and Reddy (2010) [7] and at Dharwad by Channappagoudar *et al.* (2008) [3].

Effect on weed parameters: The data indicated that weed density, weed dry weight and WCE and WI differed significantly due to different weed management treatments (Table 1). Among the different herbicide treatments, Pendimethalin 38.7 CS @ 750 g a.i. ha^{-1} (PE) *fb* IC at 35 DAS recorded significantly lower weed density (4.5), weed dry weight (2.37 g m^{-2}), higher WCE (93.57%) at 60 DAS and lower weed index (6.29%) followed by Pendimethalin 30 EC @ 1000 g a.i. ha^{-1} (PE) *fb* IC at 35 DAS (5.3, 2.80 g m^{-2}, 92.40% and 8.64%, respectively), Sulfentrazone 48 SC @ 192 g a.i. ha^{-1} (PE) *fb* IC at 35 DAS (6.2, 33.24 g m^{-2}, 91.21% and 16.47%, respectively), Quizalofop-p-ethyl @ 75 g a.i. ha^{-1} (POE) *fb* IC at 35 DAS (7.2, 3.77 g m^{-2}, 89.77% and 17.74%, respectively) and Propaquizafop @ 75 g a.i. ha^{-1} (POE) *fb* IC at 35 DAS (8.2, 4.30 g m^{-2}, 88.33% and 19.28%, respectively) and were on par with Farmers practice (5.8, 3.07 g m^{-2}, 91.67% and 11.86%, respectively). Similar results were quoted by Hansraj *et al.* (2018) [4]. This was due to effective control of weeds by herbicides and inter-cultivation operation during critical period of crop-weed competition.

Effect on yield and yield parameters of sunflower: Yield and yield parameters were significantly differed due to different weed management treatments (Table 2 and 3). Among the different herbicide treatments, Pendimethalin 38.7 CS @ 750 g a.i. ha^{-1}- PE *fb* IC at 35 DAS recorded significantly higher seed yield (20.7 q ha^{-1}), capitulum diameter (15.1 cm), capitulum weight (95.4 g), 100 seed weight (5.68 g), seed yield per plant (67.55 g) and lower per cent chaffiness (5.55%) followed by Pendimethalin 30 EC @ 1000 g a.i. ha^{-1}- PE *fb* IC at 35 DAS (20.2 q ha^{-1}, 14.8 cm, 93.2 g, 5.65 g, 65.99 g and 5.87%, respectively), Sulfentrazone @ 192 g a.i. ha^{-1}- PE *fb* IC at 35 DAS (18.5 q ha^{-1}, 13.8 cm, 90.1 g, 5.56 g, 63.38 g and 6.19%, respectively), Quizalofop-p-ethyl @ 75 g a.i. ha^{-1}- POE *fb* IC at 35 DAS (18.2 q ha^{-1}, 13.6 cm, 88.4 g, 5.48 g, 63.15 g and 6.32%, respectively), Propaquizafop @ 75 g a.i. ha^{-1}- POE *fb* IC at 35 DAS (17.8 q ha^{-1}, 13.5 cm, 87.2 g, 5.45 g, 62.93 g and 6.44%, respectively) and Fenoxaprop-p-ethyl @ 50 g a.i. ha^{-1}- POE *fb* IC at 35 DAS (17.8 q ha^{-1}, 13.4 cm, 87.1 g, 5.42 g, 62.02 g and 6.55%, respectively) and were on par with Farmers practice (19.5 q ha^{-1}, 14.9 cm, 91.9 g, 5.65 g, 68.08 g and 5.94%, respectively). Similar results were reported by Baskaran and Kavimani (2014) [2] and Hansraj *et al.* (2018) [4]. This was due to better control of weeds which reduced the competition by weeds for natural resources and resulted in increased yield parameters which in turn enhanced the seed yield. Oil content of sunflower was not influenced by any of the weed management practices.

Economics

Net returns and benefit cost (B: C) ratio were significantly varied due to different weed management treatments (Table 3). Among the different herbicide treatments, Pendimethalin 38.7 CS @ 750 g a.i. ha^{-1}- PE *fb* IC at 35 DAS recorded significantly higher net returns (₹ 43,074 ha^{-1}) and B: C ratio (2.46) followed by Pendimethalin 30 EC @ 1000 g a.i. ha^{-1}- PE *fb* IC at 35 DAS (₹ 41,415 ha^{-1} and 2.42, respectively), Sulfentrazone 48 SC @ 192 g a.i. ha^{-1}- PE *fb* IC at 35 DAS (₹ 35,665 ha^{-1} and 2.23, respectively), Fenoxaprop-p-ethyl @ 50 g a.i. ha^{-1}- POE *fb* IC at 35 DAS (₹ 33,434 ha^{-1} and 2.13, respectively), Quizalofop-p-ethyl @ 75 g a.i. ha^{-1}- POE *fb* IC at 35 DAS (₹ 33,147 ha^{-1} and 2.09, respectively) and Propaquizafop @ 75 g a.i. ha^{-1}- POE *fb* IC at 35 DAS (₹ 33,082 ha^{-1} and 2.13, respectively) and were on par with Farmers practice (₹ 34,193 ha^{-1} and 2.01, respectively). Similar findings were reported by Patel *et al.* (2006) [6]. This was a result of higher seed yield in these treatments. B: C ratio was higher in herbicide treatments than farmers practice where hand weeding was practiced.

Conclusion

Findings of the present investigation revealed that both pre-emergent herbicides; Pendimethalin 30 EC @ 1000 g ha^{-1}, Pendimethalin 38.7 CS @ 750 g ha^{-1}, Sulfentrazone @ 192 g ha^{-1} and post-emergent herbicides; Propaquizafop @ 75 g ha^{-1}, Quizalofop-p-ethyl @ 75 g ha^{-1}, Fenoxaprop-p-ethyl @ 50 g ha^{-1} in addition with inter-cultivation at 35 DAS were effective in managing the weeds with higher WCE, seed yield, net returns and benefit cost ratio. Hence, these herbicides with inter-cultivation could be used as alternative weed management practices.

Table 1: Weed density, weed dry weight, weed control efficiency (WCE) at 60 DAS and weed index (WI) of sunflower as influenced by weed management practices

Treatment	Dose (g ha^{-1})	Weed density (m^{-2})	Weed dry weight (g m^{-2})	WCE (%)	WI (%)
T_1: Pendimethalin 30 EC	1000	4.95* (24.0)	3.62 (12.63)	65.72	24.98
T_2: Pendimethalin 38.7 CS	750	5.08 (25.3)	3.72 (13.33)	63.82	25.70
T_3: Sulfentrazone	192	5.35 (28.2)	3.91 (14.83)	59.74	33.67
T_4: Propaquizafop	75	5.56 (30.5)	4.07 (16.09)	56.32	40.50
T_5: Quizalofop-p-ethyl	75	5.69 (32.0)	4.16 (16.84)	54.29	40.77
T_6: Fenoxaprop-p-ethyl	50	5.91 (34.5)	4.31 (18.16)	50.71	41.49
T_7: Pendimethalin 30 EC *fb* IC at 35 DAS	1000	2.42 (5.3)	1.82 (2.80)	92.40	8.64
T_8: Pendimethalin 38.7 CS *fb* IC at 35 DAS	750	2.23 (4.5)	1.69 (2.37)	93.57	6.29
T_9: Sulfentrazone *fb* IC at 35 DAS	192	2.58 (6.2)	1.93 (3.24)	91.21	16.47
T_{10}: Propaquizafop *fb* IC at 35 DAS	75	2.93 (8.2)	2.18 (4.30)	88.33	19.28
T_{11}: Quizalofop-p-ethyl *fb* IC at 35 DAS	75	2.77 (7.2)	2.06 (3.77)	89.77	17.74
T_{12}: Fenoxaprop-p-ethyl *fb* IC at 35 DAS	50	3.13 (9.3)	2.32 (4.91)	86.67	19.41
T_{13}: Farmers practice (2 HW at 15 & 30 DAS + 1 IC at 40 DAS)		2.52 (5.8)	1.89 (3.07)	91.67	11.86
T_{14}: Weed free check		0.71 (0.0)	0.71 (0.00)	100.00	0.00
T_{15}: Weedy check		8.35 (69.5)	6.10 (36.84)	0.00	62.72
S. Em. ±		0.18	0.13	3.51	4.12
C. D. (P=0.05)		0.53	0.38	10.16	11.92

* Transformed values ($\sqrt{x+0.5}$), figures in the parentheses indicate original values, *fb*: followed by, IC: inter-cultivation, DAS: days after sowing, HW: hand weeding, BLWs: broad-leaved weeds

Table 2: Capitulum diameter, capitulum weight, per cent chaffiness, 100 seed weight and seed yield per plant of sunflower as influenced by weed management practices

Treatment	Dose (g ha^{-1})	Capitulum diameter (cm)	Capitulum weight (g)	Per cent chaffiness (%)	100 seed weight (g)	Seed yield per plant (g)
T_1: Pendimethalin 30 EC	1000	12.7	82.6	7.11	5.26	55.52
T_2: Pendimethalin 38.7 CS	750	12.6	84.2	6.95	5.24	55.69
T_3: Sulfentrazone	192	12.2	79.9	7.07	5.17	54.36
T_4: Propaquizafop	75	11.3	76.2	7.61	5.07	52.69
T_5: Quizalofop-p-ethyl	75	11.5	76.8	7.42	5.02	53.81
T_6: Fenoxaprop-p-ethyl	50	11.2	75.7	7.56	5.09	51.95
T_7: Pendimethalin 30 EC *fb* IC at 35 DAS	1000	14.8	93.2	5.87	5.65	65.99
T_8: Pendimethalin 38.7 CS *fb* IC at 35 DAS	750	15.1	95.4	5.55	5.68	67.55
T_9: Sulfentrazone *fb* IC at 35 DAS	192	13.8	90.1	6.19	5.56	63.38
T_{10}: Propaquizafop *fb* IC at 35 DAS	75	13.5	87.2	6.44	5.45	62.93
T_{11}: Quizalofop-p-ethyl *fb* IC at 35 DAS	75	13.6	88.4	6.32	5.48	63.15
T_{12}: Fenoxaprop-p-ethyl *fb* IC at 35 DAS	50	13.4	87.1	6.55	5.42	62.02
T_{13}: Farmers practice (2 HW at 15 & 30 DAS + 1 IC at 40 DAS)		14.9	91.9	5.94	5.65	68.08
T_{14}: Weed free check		15.6	99.6	5.37	5.87	69.77
T_{15}: Weedy check		10.1	67.4	9.92	4.62	46.43
S. Em. ±		0.7	3.5	0.26	0.25	3.35
C. D. (P=0.05)		2.0	10.1	0.77	0.73	9.69

fb: followed by, IC: inter-cultivation, DAS: days after sowing, HW: hand weeding

Table 3: Oil content, seed yield, net returns and benefit cost ratio (B: C ratio) of sunflower as influenced by weed management practices

Treatment	Dose (g ha^{-1})	Oil content (%)	Seed yield (q ha^{-1})	Net returns (₹ ha^{-1})	B: C ratio
T_1: Pendimethalin 30 EC	1000	38.65	16.6	30,280	2.09
T_2: Pendimethalin 38.7 CS	750	38.68	16.4	29,559	2.06
T_3: Sulfentrazone	192	38.57	14.7	23,877	1.87
T_4: Propaquizafop	75	38.88	13.2	18,167	1.65
T_5: Quizalofop-p-ethyl	75	39.01	13.1	16,820	1.58
T_6: Fenoxaprop-p-ethyl	50	38.60	12.9	17,854	1.65
T_7: Pendimethalin 30 EC *fb* IC at 35 DAS	1000	39.08	20.2	41,415	2.42
T_8: Pendimethalin 38.7 CS *fb* IC at 35 DAS	750	38.72	20.7	43,074	2.46
T_9: Sulfentrazone *fb* IC at 35 DAS	192	39.08	18.2	35,665	2.23
T_{10}: Propaquizafop *fb* IC at 35 DAS	75	38.95	17.8	33,082	2.13
T_{11}: Quizalofop-p-ethyl *fb* IC at 35 DAS	75	38.53	18.5	33,147	2.09
T_{12}: Fenoxaprop-p-ethyl *fb* IC at 35 DAS	50	38.62	17.8	33,434	2.16
T_{13}: Farmers practice (2 HW at 15 & 30 DAS + 1 IC at 40 DAS)		38.46	19.5	34,193	2.01
T_{14}: Weed free check		38.74	22.1	33,835	1.78
T_{15}: Weedy check		38.50	8.6	4,020	1.15
S. Em. ±		0.16	1.1	3,810	0.12
C. D. (P=0.05)		NS	3.2	11,036	0.35

fb: followed by, IC: inter-cultivation, DAS: days after sowing, HW: hand weeding

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