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RESEARCH PAPER

Effective weed management practices in *kharif* sorghum (*Sorghum bicolor* L.) for higher yield and economics

S. S. VINAYAKA[1], D. KRISHNAMURTHY[2], A. S. CHANNABASAVANNA[3], Y. M. RAMESHA[4] AND MANJUNATH BHANUVALLI[5]

[1]Department of Agronomy, [2]AICRP on Sorghum, Agricultural Reseach Station, Hagari
[3]Directorate of Research, [4]Agricultural Reseach Station, Dhadesugur,
[5]Agricultural Extension Education Centre, Hadagali, Karnataka, India
Univeristy of Agricultural Sciences, Raichur - 584 102
E-mail: murthyagron@gmail.com

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Abstract: A Field experiment was conducted during *kharif* 2018 on deep black soilwith neutral reaction (pH 7.50), organic carbon (5.4 g kg^{-1}), available nitrogen (262.00 kg ha^{-1}), available phosphorus (39.25 kg ha^{-1}) and available potassium (307.00 kg ha^{-1}) at Agricultural Research Station, Hagari, Ballari. The experiment was replicated thrice in Randomized Complete Block Design. There were twelve treatments comprising of weed management practices. The dominant weeds observed in the experimental fields were among grasses *Digitaria bicornis,* while in broad leaved weeds, *Abutilon hirtum* and among sedges, *Cyperus rotundus*. Significantly lower density of grasses, sedges, and broad leaved weeds, weed dry weight, weed index (%) and higher weed control efficiency throughout the crop growth period was noticed in sequential pre-emergence application of atrazine 50 WP @ 0.50 kg a.i.ha^{-1}fb 2, 4-D Ethyl Ester 38 EC @ 0.90 kg a.i.ha^{-1} as PoE at 30 days after sowing 30.5 g, 4777 kg ha^{-1}, 9577 kg ha^{-1}, 16.72 %, ₹ 1,11,187ha^{-1}, ₹ 68, 425 ha^{-1} and 2.60, respectively) was recorded with pre-emergence application of atrazine 50 WP @ 0.50 kg a.i.ha^{-1}fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i.ha^{-1} as PoE at 30 DAS except weed free and it was on par with hand weeding at 20 DAS and 1 IC at 40 DAS and 2, 4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb 1 IC at 40 DAS as compared to other treatments.

Key words: Economics, Growth, Sorghum, Weed management

Introduction

Sorghum (*Sorghum bicolor* L.) is the fifth most important cereal in the world after wheat, rice, maize and barley. It is considered as king of millets and extensively grown in semi-arid tracks of Africa, China and India. India presently produces about 4.56 million tonnes of sorghum grain from an area of 5.62 m ha with a productivity of 812 kg ha^{-1} (Anon., 2016). In Karnataka, sorghum occupies about 0.94 m ha area and annual production of 0.84 m t with a productivity of 892 kg ha^{-1} (Anon., 2016). In Karnataka, sorghum is mainly grown in Belgaum, Vijayapura, Bagalkot, Dharwad, Ballari and Gadag districts both in *kharif* and *rabi* seasons.

Sorghum growing area is more under *rabi* season mainly due to lower infestation of weeds during *rabi* season as compared to *kharif* season. Use of high yielding varieties/ hybrids, fertilizer management, weed management, irrigation management, plant protection *etc.* are the important factors responsible for increasing the sorghum productivity. Weeds are one of the major problems in limiting the productivity of sorghum during *kharif* season. Weed competition in grain sorghum reduces yields, causes harvesting losses and increases seed content of the soil seed bank. Weed infestations in the early growing season will reduce yields significantly. Comparing the production potential of sorghum, the low productivity in India is attributed to several reasons. Among them, weed competition is major constraint. Presence of weeds during critical period reduced the yield of sorghum to the extent of 15-40 %. Chemical method of weed control has become efficient, time saving and cheaper with the introduction of herbicides. Use of pre-emergence herbicides assumes greater importance in the view of their effectiveness from initial stages, while post emergence herbicides may help in avoiding the problem of weeds at later stages. Chemical weed control is a better supplement to conventional method however the weed emergence pattern, application timing and stage of crop are important in chemical control. Continuous use of herbicides over a prolonged time leads to development of resistance in weeds making them difficult to control. Traditional hand weeding is the most efficient and widely adopted practice of weed management but it is labour intensive, time consuming and not economical due to high wage rates. Mechanical equipment can be time saving during peak operation, resulting in higher output per worker and reduction in the cost of weeding. However, neither herbicides nor mechanical methods are adequate for consistent and acceptable weed control. The integration of herbicide with some cultural operations or use of pre-emergence and post emergence herbicides in combination with mechanical methods can be more successful. Keeping in view the above facts, the present investigation was carried out to study the "Effect of weed management practices on weed dynamics, growth, yield and economicsof *kharif* grain sorghum" at Agricultural Research Station, Hagari, Ballari.

Material and methods

A field experiment was conducted at the Agricultural Research Station, Hagari, Ballari during *kharif* 2018. Agricultural Research Station, Hagari, Ballari is located on 15° 14' N latitude

and 77° 07' E longitude with an altitude of 414 meters above the mean sea level and is located in Northern Dry Zone of Karnataka (Zone-III). Twelve treatments comprising of weed management practices *viz.,* T_1: Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE, T_2: Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 1 IC at 40 DAS, T_3: Pendimethalin 38.7 CS @ 0.6773 kg a.i. ha^{-1} as PE, T_4: Pendimethalin 38.7 CS @ 0.6773 kg a.i. ha^{-1} as PE fb 1 Intercultivation (IC) at 40 DAS, T_5: Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE, T_6: Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE fb 1 IC at 40 DAS, T_7: 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS, T_8: 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb 1 IC at 40 DAS, T_9: Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS, T_{10}: Hand weeding at 20 DAS and 1 IC at 40 DAS, T_{11}: Weed free (IC at 20 & 40 DAS and HWat 30 DAS), T_{12}: Weedy check were evaluated in randomized block design with three replications. The recommended dose of inorganic and organic manures (100:75:37 $N:P_2O_5:K_2O$ + FYM @ 5 t ha^{-1}) were applied as per the treatments. FYM was applied before 15 days of sowing for better decomposition and 50 % nitrogen and entire dose of phosphorous and potassium were given in the form of urea, diammonium phosphate (DAP) and Muriate of potash, respectively and band placed at the time of sowing and remaining 50 % nitrogen was applied at 4 weeks after sowing. Fertilizers were applied 4-5 cm deep and 5 cm away from the seed as a basal dose. The soil of the experiment was deep black soils with neutral in reaction (pH 7.50), organic carbon (5.1 g kg^{-1}), available nitrogen (262 kg ha^{-1}), available phosphorous (39.3kg ha^{-1}) and available potassium (307.0 kg ha^{-1}). The seeds of CSH-25, hybrid (7.5 kg ha^{-1}) were sown at 45 cm between rows and 15 cm between the seeds and two seeds per hill were dibbled in furrows and were covered with soil. The recommended packages of practices were adopted for crop production and crop was harvested at its physiological maturity.

Pre-emergent (PRE) application of atrazine 50 % EC and pendimethalin 38.7 CS wereapplied on the day of sowing and post emergent (PoE) spray of 2,4-D Ethyl Ester 38 EC was applied at 2-7 leaf stage of weed (30 days after sowing). Intercultivation was done at 20 and 40 days after sowing with cycle weederand hand weedings were done on 20, 30 and 40 days after sowing as per the treatments. Data on weed population species wise (No. m^{-2}) were recorded at 20, 40, 60 days after sowing (DAS) and at harvest at three spots per plot. These weeds were categorized as grasses, sedge and broad leaf weeds and expressed as number m^{-2} and averaged over two random spots per plot using and like wise weed dry weight was recorded. Weed control efficiency (WCE) was worked out taking weed dry weight into consideration. Further, dataon weed density and dry weight was subjected to square root transformation ($\sqrt{x+0.25}$) before analysis.

The field experiment was laid out in Randomized Block Design with prescribed treatments. The observation of phytotoxicity on sorghum and chickpea plants were done on the basis of phytotoxicity rating scale (PRS) for the applied testing herbicides at 3, 6, 9 and 12 DAT (days after treatment). The parameters on phytotoxicity were taken as leaf epinasty and hyponasty, necrosis (leaf tips and margins) and wilting. The observation on the level of phytotoxicity through visual assessment of crop response was rated in the scale of 0-10 (0 = No adverse effect of herbicide on chickpea and 10= 100 % adverse effect of herbicide on sorghum).

Data on growth attributes were recorded from 5 randomly selected plants, whereas yield attributes and yield data recorded from net plot at harvest. For economic study prevailing market price was used for different outputs and inputs. All the parameters were subjected for statistical analysis and interpretation as outlined by Panse and Sukhatme (1967).

Results and discussion

Effect on weeds: The prominent weed species in the experimental plot were *Cynodondactylon, Brachiariareptans, Chlorisinflata, Dactylocteniumaegeptium, Digitariabicornis, Dinebraretroflexa* and *Cynotisculcullata* among grassy weeds; *Corchorusaestuans, Abutilon hirtum, Amaranthusviridis, Aristolachiabractiata, Euphorbia humifusa,* and *Digeramuricate* among the broad leaf weeds and *Cyperusrotundus*was the only sedge. Similar weed flora was reported by Thakur *et al*. (2016) at Indore and Sreeram *et al*. (2016) at Bapatla.

Density of weeds: At 60 days after sowing, sequential application of atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS recorded significantly lower density of total weeds (4.88 m^{-2}) and it was on par with hand weeding at 20 DAS and 1 IC at 40 DAS (5.08 m^{-2}) compared to other treatments (Table 1). Significantly higher number of broad leaved weeds recorded with weedy check (10.89 m^{-2}). This is in conformity with the findings of Sharma *et al*. (2000), Kavimani *et al*. (2002) and Thakur *et al*. (2016).

Dry weight of weeds: At 60 DAS, sequential application of pre-emergence herbicide atrazine 50 WP @ 0.50 kg a.i. ha^{-1}fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS recorded significantly lower total dry weight of weeds (4.67 g m^{-2}) and it was on par with the hand weeding at 20 DAS and 1 IC at 40 DAS (4.84 g m^{-2}) and 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb 1 IC at 40 DAS (4.96 g m^{-2}) (Table 2). It was mainly due to the lower population of grasses, broad-leaved weeds and sedges resulted in lower dry weight of weeds. These results are conformity with findings of Grima and Chinawong (2005) and Ramesh and Nadanassababady (2005).

Weed control efficiency: At 60 DAS, sequential pre-emergence application of atrazine 50 WP @ 0.50 kg a.i. ha^{-1}fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS recorded significantly higher weed control efficiency (85.26) and it was found to be on par with hand weeding at 20 DAS and 1 IC at 40 DAS (84.16 %) and 2,4-D Ethyl Ester 38 EC @

Table 1. Effect of weed management prctices on density of total weeds at different growth stages of sorghum

Treatments	Density of total weeds (Number m^{-2})		
	20 DAS	40 DAS	60 DAS
T_1 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE	3.10 (9.40)	5.29 (27.73)	7.12 (50.50)
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	3.24 (10.27)	5.20 (26.78)	5.98 (35.53)
T_3 : Pendimethalin 38.7 CS @ 0.6773 kg a.i. ha^{-1} as PE	3.20 (10.00)	5.81 (33.51)	7.96 (63.17)
T_4 : Pendimethalin 38.7 CS @ 0.6773 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	3.15 (9.67)	5.59 (31.04)	7.16 (50.97)
T_5 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE	3.13 (9.60)	5.68 (31.97)	7.82 (60.83)
T_6 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE fb one IC at 40 DAS	3.06 (9.13)	5.53 (30.29)	7.02 (49.03)
T_7 : 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	5.39 (28.83)	5.48 (29.78)	6.38 (40.50)
T_8 : 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb one IC at 40 DAS	5.41 (29.03)	5.57 (30.84)	5.11 (25.90)
T_9 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	2.96 (8.53)	3.77 (13.96)	4.88 (23.60)
T_{10} : HW at 20 DAS and one IC at 40 DAS	5.43 (29.27)	3.82 (14.35)	5.08 (25.60)
T_{11}: Weed free (IC at 20 & 40 DAS and HW at 30 DAS)	5.15 (26.27)	3.17 (9.81)	4.38 (19.00)
T_{12}: Weedy check	5.58(30.93)	8.40(70.37)	10.89 (118.27)
S.Em.±	0.09	0.07	0.10
C.D. (P=0.05)	0.28	0.19	0.29

Note:

* Figures in parentheses indicate original values Transformation- ($\sqrt{x+0.25}$) WP: Wettable powder PE: Pre-emergence
fb: Followed by IC: Inter cultivation DAS: Days after sowing CS: Capsulated suspension
EC: Emulsified concentrate PoE: Post emergence HW: Hand Weeding

Table 2. Total dry weight of weeds at different growth stages of sorghum due to different weed management practices

Treatments	Total dry weight of weeds (g m^{-2})		
	20 DAS	40 DAS	60 DAS
T_1 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE	3.31 (10.70)	5.96 (35.40)	6.88 (47.16)
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	3.23 (10.22)	5.69 (32.17)	5.86 (34.11)
T_3 : Pendimethalin 38.7 CS @ 0.6773 kg a.i. ha^{-1} as PE	3.16 (9.79)	5.99 (35.67)	8.30 (68.63)
T_4 : Pendimethalin 38.7 CS @ 0.6773 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	3.14 (9.63)	5.90 (34.54)	7.19 (51.53)
T_5 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i.ha^{-1} (Tank mix) as PE	3.52 (12.15)	6.54 (42.51)	7.64 (58.10)
T_6 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE fb one IC at 40 DAS	3.40 (11.36)	6.33 (39.83)	6.91 (47.48)
T_7 : 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	5.47 (29.69)	5.47 (29.67)	6.22 (38.55)
T_8 : 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb one IC at 40 DAS	5.38 (28.68)	5.18 (26.63)	4.96 (24.36)
T_9 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	2.90 (8.15)	4.99 (24.69)	4.67 (21.54)
T_{10} : HW at 20 DAS and one IC at 40 DAS	5.66 (31.87)	5.07 (25.43)	4.84 (23.16)
T_{11}: Weed free (IC at 20 & 40 DAS and HW at 30 DAS)	5.38 (28.76)	3.77 (14.04)	3.43 (11.53)
T_{12}: Weedy check	5.89(34.50)	8.61(73.84)	12.10 (146.13)
S.Em.±	0.09	0.13	0.12
C.D. (P=0.05)	0.27	0.38	0.34

Note:

* Figures in parentheses indicate original values Transformation- ($\sqrt{x+0.25}$) WP: Wettable powder PE: Pre-emergence
fb: Followed byIC: Inter cultivation DAS: Days after sowing CS: Capsulated suspension EC: Emulsified concentrate
PoE: Post emergence HW: Hand Weeding

0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb 1 IC at 40 DAS (83.33 %) (Table 3). It was due to lower weed population and lower dry weight of weeds in these treatments. These results are in corroborate with the findings of Agrawal *et al*. (2006), Patel *et al*. (2006), Priya and Kubsad (2013) and Shantveerayya *et al.* (2012).

Phytotoxicity of herbicides on sorghum: There was no phototoxic injury (0.00) on crop at 3, 6, 9 and 12 days after spray with pre-emergence or post emergence application of atrazine and 2,4-D Ethyl Ester (Table 4). At six and ninth days after spray, slight injury or discolouration of leaves and stem was observed in pre-emergence application of Pendimethalin 38.7 CS @ 0.6773 kg a.i.$ha^{-1}$and atrazine 50 WP @ 0.25 kg a.i.ha^{-1} + pendimethalin 38.7 CS @ 0.3387 kg a.i.ha^{-1} (Tank mix) and it was recovered after twelve days of spray. There was no phototoxic injury on crop was observed in other treatments. There was no phototoxic injury on crop was observed 12th days after spraying of herbicides on sorghum.

Table 3. Weed control efficiency at different growth stages of sorghum due to different weed management practices

Treatments	Weed control efficiency (%)		
	20 DAS	40 DAS	60 DAS
T_1 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE	68.90	51.99	67.73
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	70.44	56.36	76.66
T_3 : Pendimethalin 38.7 CS @ 0.6773 kg a.i. ha^{-1} as PE	71.69	51.54	53.04
T_4 : Pendimethalin 38.7 CS @ 0.6773 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	72.10	53.19	64.74
T_5 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i.ha^{-1} (Tank mix) as PE	64.74	42.36	60.24
T_6 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE fb one IC at 40 DAS	67.13	45.96	67.52
T_7 : 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	12.40	59.78	73.62
T_8 : 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i.ha^{-1} as PoE at 30 DAS fb one IC at 40 DAS	16.88	58.52	83.33
T_9 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	76.40	65.52	85.26
T_{10} : HW at 20 DAS and one IC at 40 DAS	7.67	63.76	84.16
T_{11}: Weed free (IC at 20 & 40 DAS and HW at 30 DAS)	16.59	81.02	90.47
T_{12}: Weedy check	0.00	0.00	0.00
S.Em.±	2.60	2.00	0.99
C.D. (P=0.05)	7.63	5.85	2.90

Note:
WP: Wettable powder PE: Pre-emergence fb: Followed by HW: Hand weeding
PoE: Post emergence IC: Inter cultivation DAS: Days after sowing CS: Capsulated suspension
EC: Emulsified concentrate

Table 4. Phytotoxicity rating of different herbicides on sorghum crop at different days after application

Treatments	Phytotoxicity symptoms (days after application of herbicides)			
	3	6	9	12
T_1 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE	0	0	0	0
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	0	0	0	0
T_3 : Pendimethalin 38.7 CS @ 0.6773 kg a.i. ha^{-1} as PE	0	1	2	0
T_4 : Pendimethalin 38.7 CS @ 0.6773 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	0	1	3	0
T_5 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE	0	1	3	0
T_6 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE fb one IC at 40 DAS	0	1	2	0
T_7 : 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	0	0	0	0
T_8 : 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb one IC at 40 DAS	0	0	0	0
T_9 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	0	0	0	0
T_{10} : HW at 20 DAS and one IC at 40 DAS	0	0	0	0
T_{11}: Weed free (IC at 20 & 40 DAS and HW at 30 DAS)	0	0	0	0
T_{12}: Weedy check	0	0	0	0

Note:
WP: Wettable powder PE: Pre-emergence fb: Followed by HW: Hand weeding
PoE: Post emergence IC: Inter cultivation DAS: Days after sowing CS: Capsulated suspension
EC: Emulsified concentrate

Residual effect of herbicides on succeeding chickpea crop: The germination percentage, plant height and number of branches of chickpea were recorded at 45 DAS and found that, treatments did not differ significantly (Table 3). The sorghum - chickpea is the prominent sequence in the experimental area. Hence, the residual effects of these treatments were studied on chickpea by bioassay studies (germination test) and the crop was examined for its growth parameters like plant height and branches in main field. The data showed that non-significant differences between chemical weed management practices and non-chemical treated plots (hand weeding, weed free and weedy check) indicating no adverse effect of applied herbicides on succeeding crop and confirmed no residual effect of the herbicides tried in the experiment. Jayakumar *et al*. (2003) obtained similar results in sorghum.

Growth parameters: Significantly taller plants, higher leaf area, leaf area index and total dry matter production (161.7 cm, 24.9 dm^2 plant^{-1}, 3.82 and 132.1 g plant^{-1}, respectively at harvest) was recorded in weed free check. Among other weed management practices, sequential pre-emergence application of atrazine 50 WP @ 0.50 kg a.i.ha^{-1}fb 2,4-D Ethyl Ester 38 EC @

Table 5. Growth parameters of *kharif* sorghum due to different weed management practices

Treatments	Plant height (cm)	Leaf area (dm^2 $plant^{-1}$)	Leaf area index	Total dry matter accumulation (g $plant^{-1}$)
T_1 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE	156.2	21.0	3.24	160.6
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	158.7	21.9	3.37	175.7
T_3 : Pendimethalin 38.7 CS @0.6773 kg a.i. ha^{-1} as PE	150.4	17.6	2.74	141.3
T_4 : Pendimethalin 38.7 CS @0.6773 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	152.5	20.8	3.21	155.8
T_5 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1}(Tank mix) as PE	154.0	20.7	3.20	147.5
T_6 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE fb one IC at 40 DAS	154.8	20.9	3.22	157.2
T_7 : 2,4-D Ethyl Ester 38EC@ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	158.0	21.0	3.24	167.9
T_8 : 2,4-D Ethyl Ester 38EC@ 0.90 kg a.i.ha^{-1} as PoE at 30 DAS fb one IC at 40 DAS	159.2	24.0	3.68	180.1
T_9 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 2,4-D Ethyl Ester 38EC @ 0.90 kg a.i. ha^{-1}as PoE at 30 DAS	161.3	24.8	3.80	187.4
T_{10} : HW at 20 DAS and one IC at 40DAS	160.0	24.1	3.70	184.1
T_{11} : Weed free(IC at 20 & 40 DAS and HW at 30 DAS)	161.7	24.9	3.82	198.4
T_{12} : Weedy check	141.6	16.2	2.53	132.1
S.Em.±	1.6	0.4	0.06	2.8
C.D. (P=0.05)	4.7	1.1	0.17	8.1

Note:
WP: Wettable powder PE: Pre-emergence fb: Followed by HW: Hand weeding
PoE: Post emergence IC: Inter cultivation DAS: Days after sowing CS: Capsulated suspension
EC: Emulsified concentrate

Table 6. Yield parameters of *kharif* sorghum due to different weed management practices

Treatments	Length of ear head (cm)	Number of grains ear $head^{-1}$	Test weight (g 1000 $grains^{-1}$)
T_1 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE	28.1	1871	29.3
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	28.8	1979	29.6
T_3 : Pendimethalin 38.7 CS @0.6773 kg a.i. ha^{-1} as PE	26.1	1685	27.5
T_4 : Pendimethalin 38.7 CS @0.6773 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	27.4	1820	28.7
T_5 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1}(Tank mix) as PE	26.9	1711	28.5
T_6 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE fb one IC at 40 DAS	27.7	1831	28.9
T_7 : 2,4-D Ethyl Ester 38EC@ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	28.5	1921	29.4
T_8 : 2,4-D Ethyl Ester 38EC@ 0.90 kg a.i.ha^{-1} as PoE at 30 DAS fb one IC at 40 DAS	29.4	2010	30.2
T_9 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 2,4-D Ethyl Ester 38EC @ 0.90 kg a.i. ha^{-1}as PoE at 30 DAS	30.0	2229	30.5
T_{10} : HW at 20 DAS and one IC at 40DAS	29.7	2149	30.3
T_{11} : Weed free(IC at 20 & 40 DAS and HW at 30 DAS)	30.8	2321	31.0
T_{12} : Weedy check	25.6	1495	27.3
S.Em.±	0.5	79	0.4
C.D. (P=0.05)	1.4	231	1.2

Note:
WP: Wettable powder PE: Pre-emergence fb: Followed by HW: Hand weeding
PoE: Post emergence IC: Inter cultivation DAS: Days after sowing CS: Capsulated suspension
EC: Emulsified concentrate

0.90 kg a.i.ha^{-1} as PoE at 30 DAS, HW at 20 DAS, HW at 20 DAS and one IC at 40 DAS and 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i.ha^{-1} as PoE at 30 DAS fb one IC at 40 DAS recorded higher leaf area and leaf area index (Table 5). Lower leaf area and leaf area index was recorded with weedy check. The higher dry matter production in these treatments might be due to the reduced competition from weeds and increased availability of resources like nutrients, soil moisture and light which paved the way for improvement of crop stature as reflected by taller plants and higher leaf area, which consequently increased the biomass of the crop. Whereas, the lower total plant dry weight was recorded in weedy check, as a result of severe weed

Table 7. Grain yield, straw yield and harvest index of *kharif* sorghum under different weed management practices

Treatments	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
T_1 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE	3976	8633	31.01
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	4080	9131	31.24
T_3 : Pendimethalin 38.7 CS @0.6773 kg a.i. ha^{-1} as PE	3292	7929	29.33
T_4 : Pendimethalin 38.7 CS @0.6773 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	3489	8466	28.94
T_5 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1}(Tank mix) as PE	3367	8396	28.61
T_6 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE fb one IC at 40 DAS	3662	8579	29.48
T_7 : 2,4-D Ethyl Ester 38EC@ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	4045	8858	31.30
T_8 : 2,4-D Ethyl Ester 38EC@ 0.90 kg a.i.ha^{-1} as PoE at 30 DAS fb one IC at 40 DAS	4549	9328	32.62
T_9 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 2,4-D Ethyl Ester 38EC @ 0.90 kg a.i. ha^{-1}as PoE at 30 DAS	4602	9577	33.10
T_{10}: HW at 20 DAS and one IC at 40DAS	4582	9428	32.81
T_{11}: Weed free(IC at 20 & 40 DAS and HW at 30 DAS)	4777	9727	33.49
T_{12}: Weedy check	2917	7346	28.47
S.Em.±	163	504	1.74
C.D. (P=0.05)	478	1478	NS

Note:
WP: Wettable powder PE: Pre-emergence fb: Followed by HW: Hand weeding
PoE: Post emergence IC: Inter cultivation DAS: Days after sowing CS: Capsulated suspension
EC: Emulsified concentrate

Table 8. Economics of *kharif* sorghum cultivation under different weed management practices

Treatments	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	Benefit cost ratio
T_1 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE	40744	96786	56042	2.38
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	43332	99868	56536	2.30
T_3 : Pendimethalin 38.7 CS @0.6773 kg a.i. ha^{-1} as PE	40877	81705	40828	2.00
T_4 : Pendimethalin 38.7 CS @0.6773 kg a.i. ha^{-1} as PE fb one IC at 40 DAS	43559	86719	43160	1.99
T_5 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1}(Tank mix) as PE	41558	84132	42574	2.02
T_6 : Atrazine 50 WP @ 0.25 kg a.i. ha^{-1} + Pendimethalin 38.7 CS @ 0.3387 kg a.i. ha^{-1} (Tank mix) as PE fb one IC at 40 DAS	44337	90392	46055	2.04
T_7 : 2,4-D Ethyl Ester 38EC@ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS	40820	99023	58203	2.43
T_8 : 2,4-D Ethyl Ester 38EC@ 0.90 kg a.i.ha^{-1} as PoE at 30 DAS fb one IC at 40 DAS	43808	109237	65429	2.49
T_9 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb 2,4-D Ethyl Ester 38EC @ 0.90 kg a.i. ha^{-1}as PoE at 30 DAS	42762	111187	68425	2.60
T_{10}: HW at 20 DAS and one IC at 40DAS	48440	110495	62055	2.28
T_{11}: Weed free(IC at 20 & 40 DAS and HW at 30 DAS)	52658	114987	62329	2.18
T_{12}: Weedy check	38771	73025	34254	1.88
S.Em.±	-	-	3098	0.05
C.D.(P=0.05)	-	-	9088	0.15

Note:
WP: Wettable powder PE: Pre-emergence fb: Followed by HW: Hand weeding
PoE: Post emergence IC: Inter cultivation DAS: Days after sowing CS: Capsulated suspension
EC: Emulsified concentrate

infestation and competition throughout the crop growth period which suppressed the growth of crop, as spelt out by Kannur (2008) and Shakoor *et al*. (2014).

Yield and yield parameters: Significantly higher grain yieldand stover yield (4602 kg ha^{-1} and 9577 kg ha^{-1}, respectively) were reported under pre-emergence application of atrazine 50 WP @ 0.50 kg a.i. ha^{-1} fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS recorded significantly higher grain yield and it was on par with hand weeding at 20 DAS and 1 IC at 40 DAS (4582 kg ha^{-1} and 9428 kg ha^{-1}, respectively) and 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb 1 IC at 40 DAS (4549 kg ha^{-1} and 9328 kg ha^{-1}, respectively) (Table 7). The higher seed yield was mainly due to maintenance of weed free environment, especially from initial by pre-emergence application of atrazine as inhibits photosynthesis and enzyme reaction and causes foliar chlorosis showing symptoms from

margin to inwards and thus mature leaves further leads to inhibition of carbohydrate synthesis weakens along with non-development of shoot and root system, resulting in subsequent death of weeds and later stage post emergence application of 2,4-D Ethyl Esterreadily absorbed and translocated within the phloem tissues and causes disruption of phloem tissues and consequent dislocation of photosynthesis symptoms and kills the plants as well as during critical growth stages of crop, reduced crop weed competition helped in better growth and development of sorghum crop resulting higher grain and stover yield. These results were in corroboration with findings of Sreeram *et al.* (2016) and Shantveerayya *et al.* (2012). There was no significant difference observed with respect to harvest index.

The data of length of ear head (cm), grain weight per ear head (g), test weight (g 1000 grains^{-1}) indicated that different weed control measures significantly increased the yield attributes over weedy check (unweeded control). Among the treatments, sequential application of atrazine 50 WP @ 0.50 kg a.i. ha^{-1} fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS recorded significantly higher length of ear head (30.0 cm), number of grains per ear head (2229), grain weight per ear head (67.98 g), test weight (30.5 g 1000 grains^{-1}) and it was found on par with hand weeding at 20 DAS and 1 IC at 40 DAS (29.7 cm, 2149, 65.11 g plant^{-1}, 30.3 g 1000 grains^{-1}, respectively) and 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb 1 IC at 40 DAS (29.4 cm, 2010, 60.65 g plant^{-1}, 30.2 g 1000 grains^{-1}, respectively) (Table 6). This may be because of lesser weeds were observed in these treatments, which might have resulted in increased nutrient, water, space and light supply to sorghum crop due to absence of crop-weed competitionand ultimately higher value of yield attributes. Shivamurugan *et al.* (2017), Kannur (2008) and Shakoor *et al*. (2014) reported similar findings.

Economics: Significantly higher gross returns, net returns and B:C were recorded with pre-emergence application of atrazine 50 WP @ 0.50 kg a.i. ha^{-1} fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS (₹ 1,11,187 ha^{-1}, ₹ 68,425 ha^{-1} and 2.60, respectively) and it was on par with 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb 1 IC at 40 DAS (₹ 1,09,237 ha^{-1}, ₹ 65,429 ha^{-1} and 2.49, respectively) (Table 8). This was due to higher gross returns and lower cost of cultivation obtained from these treatments.The results were in confirmatory with the findings of Sreenivas and Satyanarayana (1994), Priya and Kubsad (2013).

Conclusion: Based on the results of the experiment, it could be concluded that pre-emergence application of atrazine 50 WP @ 0.50 kg a.i. ha^{-1}fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS was found beneficial and recorded significantly lower weed density, weed dry weight and higher weed control efficiency. Significantly higher grain yield, stover yield, net returns and benefit-cost ratio were recorded with pre-emergence application of atrazine 50 WP @ 0.50 kg a.i. ha^{-1}fb 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS followed by 2,4-D Ethyl Ester 38 EC @ 0.90 kg a.i. ha^{-1} as PoE at 30 DAS fb 1 IC at 40 DAS.

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