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RESEARCH PAPER

Integrated weed management in *rabi* sorghum (*Sorghum bicolor* L.) under rainfed conditions

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Abstract: A field experiment was conducted to assess the impact of weed management on growth and yield of grain sorghum at the Regional Agricultural Research Station, Vijayapura during *rabi* 2022-23. The experiment was laid out in a Randomized Complete Block Design with three replications and comprised eleven treatments. These treatments included five pre-emergence herbicide treatments (Atrazine @1000 g *a.i.* ha^{-1}, Metribuzin @ 350 and 700 g *a.i.* ha^{-1}, Metolachlor @ 750 and 1500 g *a.i.* ha^{-1}) followed by two intercultivation at 30 & 60 DAS, as well as four post-emergent herbicide treatments (Metribuzin @ 350 and 700 g *a.i.* ha^{-1}, Mesotrione + Atrazine (RM) @ 550 and 825 g *a.i.* ha^{-1}) followed by one intercultivation at 60 DAS. These nine herbicide treatments were compared to a weedy check and a weed free check. The experimental results showed that weed free condition recorded minimal weed infestation, better crop growth, higher yield and economical returns. Among the herbicidal treatments, application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1}as pre-emergence followed by two intercultivations at 30 and 60 DAS recorded significantly lower weed count (1.67 m^{-2}), weed biomass (4.67 g m^{-2}) and higher weed control efficiency (92%) for total weeds at 60 DAS, with a reduced weed index of 7.21%. Additionally, this treatment led to significantly higher grain yield (1389 kg ha^{-1}), stover yield (3031 kg ha^{-1}), gross returns (₹ 73,759 ha^{-1}), net returns (₹ 40,968 ha^{-1}) and benefit cost ratio (2.25). In contrast, the weedy check treatment resulted in lower grain yield, net returns, and benefit cost ratio.

Key words: Herbicides, Intercultivation, Sorghum, Weed management

Introduction

Sorghum (*Sorghum bicolor* L.) holds a unique position among major cereals, ranking fifth globally after wheat, maize, rice, and barley. This versatile crop serves as a staple food and valuable fodder source for some of the world's arid and semi-arid tropical regions. India is one of the largest producers covering an area of 3.8 million hectare and produces 4.15 million tonnes of sorghum with an average productivity of 1092 kg ha^{-1}. In Karnataka, sorghum occupies an area of 0.61 million ha producing 0.73 million tonnes grains with a productivity of 1189 kg ha^{-1} (Indiastat, 2023). Sorghum is grown in northern Karnataka mainly as rainfed crop in *rabi* season and to a very little extent under irrigated conditions.

Weeds pose a significant challenge and serve as a limiting factor for productivity in sorghum, similar to other food crops. To control weeds in sorghum field, traditional methods of intercultivation and manual weeding are more effective. However, manual weeding alone is expensive, tedious and time consuming with labour scarcity (Rajput and Khushwah, 2005). Moreover, there has been a 24.43% decline in draught animals between 2012 and the 2019 Livestock Census data of India. Additionally, there has been a 17.05% decrease in the manual workforce employed in agriculture between 2000 and 2019, as per ILOSTAT database of World Bank. Consequently, animal-drawn mechanical and manual weeding operations have become less possible options of weed management, leading to a rapid shift towards use of herbicides for weed management.

The introduction of herbicides, especially for intensive crop production, has made chemical weed control efficient and time-saving. There are numerous herbicides available for field crops, and the use of both pre-emergence and post-emergence herbicides has made herbicidal weed control more widely accepted. Pre-emergence herbicides are particularly important due to their effectiveness from the early stages of weed growth, while post-emergence herbicides can help to prevent weed problems at later stages (Mousavi, 2001).

Among herbicides, 2,4-D and atrazine have become most commonly used herbicides for grain sorghum crop (Stahlman and Wicks, 2000; Sharma *et al*., 2000). However, 2,4-D is selective to broad-leaved weeds, while atrazine has low effectiveness against grasses and sedges (Dan *et al*., 2010). Moreover, the repeated use of atrazine has been associated with weed shifts and the development of herbicide resistance in weeds (Heap, 2020). Therefore, there is a need to explore alternative herbicides for use in sorghum cultivation.

However, it's important to note that neither herbicides nor mechanical methods alone are sufficient for consistent and effective weed control. The integration of pre-emergence and post-emergence herbicides in combination with mechanical methods has shown to be more successful (Ishya *et al*., 2007). Therefore, integrated weed management is gaining importance in management of weeds for preventing losses and increasing input-use efficiency. Given these considerations and needs, this study was conducted to investigate the weed management practices in *rabi* sorghum under rainfed conditions.

Material and methods

A field experiment was conducted during the *rabi* season of 2022 at the Regional Agricultural Research Station, Vijayapura, Karnataka on vertisols having an alkaline in reaction (pH 8.30), medium organic carbon (0.43%),low salinity (0.32 dS m^{-1}), low in available Nitrogen (165 kg N ha^{-1}), medium in available Phosphorus (18.2 kg P_2O_5 ha^{-1}), and high in available Potassium (360 kg K_2O ha^{-1}).The coordinates of the experimental site are 16°462 17" North latitude, 75°452 15" East longitude and at an altitude of 593.8 m above the mean sea level. The experimental site comes under the Northern Dry Zone of Karnataka (Zone-3). A total rainfall of 134.1 mm was recorded during the cropping period from October 2022 to March 2023.

The experiment was laid out in Randomized Complete Block Design with eleven treatments replicated thrice.These treatments included five Pre-emergence herbicides treatments (Atrazine @1000 g *a.i.* ha^{-1}, Metribuzin @ 350 and 700 g *a.i.* ha^{-1}, Metolachlor @ 750 and 1500 g *a.i.* ha^{-1}) followed by two intercultivation at 30 & 60 DAS, as well as four post-emergent herbicides treatments (Metribuzin @ 350 and 700 g *a.i.* ha^{-1}, Mesotrione + Atrazine (RM) @ 550 and 825 g *a.i.* ha^{-1}) followed by one intercultivation at 60 DAS. These nine herbicide treatments were compared to a weedy check and a weed free check. The land was ploughed once after the harvest of the previous crop, followed by two harrowings. When of sowing, the land was prepared to a fine seed bed, and the plots were laid out. The variety CSV 29R was used in the study. The fertilizer in the form of urea and diammonium phosphate (DAP) was applied as per recommended package of practice 50:25:0 kg N, P_2O_5 and K_2O per ha was applied. The crop was sown on 20th October, 2022 with a spacing of 45 × 15 cm. Harvesting was done at the harvesting maturity of the crop. As per the treatments, the net plot area was harvested by cutting the plants to the ground level. After drying, the harvested produce was weighed just before threshing to record ear weight per plot. After that, threshing was done manually. The threshed produce was winnowed and cleaned to separate grain and haulm.

The weed components and yield parameters of sorghum were recorded from the net plots and grain yield was converted to hectare basis in kilograms. The weed density (no.m^{-2}) was recorded in one square meter area at 30, 45, 60 DAS and harvest. Further, these weeds were oven dried to a constant weight at 65^0C and the dry weight of weeds was expressed in g per m^2.Later, the data on weed count and weed dry matter were transformed to square root transformation ($\sqrt{X + 0.5}$) and were subjected to statistical analysis. The weed free plot was maintained through hand weeding whenever necessary is there. Pre-emergence herbicides were sprayed uniformly in respective plots, next day after sowing of sorghum crop. While, post-emergence herbicides were applied uniformly at 30 DAS. Weed control efficiency (WCE) and weed index (WI) were worked out taking weed biomass and grain yield into consideration, respectively. The economics of each treatment was computed with prevailing market prices of that year. The yield was further computed for gross and net returns as well BC ratio to assess the productivity. The benefit-cost ratio (BCR) was worked out by dividing the gross returns by the total cost of cultivation of respective treatments. The data collected from the experiment at different growth stages and at harvest were subjected to statistical analysis as described by Gomez and Gomez (1984). The level of significance used for 'F' and 't' tests was P=0.05.

$$\text{WCE (\%)} = \frac{\text{Dry matter of weeds in weedy check} - \text{Dry matter of weeds in treated plot}}{\text{Dry matter of weeds in weedy check}} \times 100$$

$$\text{WCE (\%)} = \frac{\text{Grain yield from weed free check} - \text{Grain yield from the treated plot}}{\text{Grain yield from weed free check}} \times 100$$

Results and discussion

Weed flora

The dominantweed species observed in the experimental field were, *Brachiaria reptans, Cynodon dactylon Pers., Dactyloctenium aegyptium, Digitaria sanguinalis, Dinebra retroflexa* and *Rotboellia cochinchinensis*, among monocot weeds and *Acalypha indica, Amaranthus spinosus, Convolvus arvensis, Digera arvensis, Euphorbia geniculate, Euphorbia hirta, Lactuca serriola, Parthenium hysterophorus, Phyllanthus maderaspatensis, Phyllanthus niruri, Trichodesma zeylanicum* and *Tridax procumbens* among dicot weeds. However, there was no sedges were observed in the experimental site.

Effect on weeds

Weed-management practices significantly reduced the weed population and their dry weight as compared to weedy check across various growth stages, including 30, 45, 60 DAS and at harvest (Table 1). The pre-emergence application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} along with two intercultivation at 30 and 60 DAS, consistently resulted in significantly lower total weed numbers (4.67, 3.33, 1.67 and 2.33 respectively). In contrast, the weedy check plot consistently showed significantly higher number of total weeds per square meter (33.33, 37.00, 39.67 and 42.00 respectively) compared to all other treatments.

Weed dry weight, indicating the growth potential and competitive ability of weeds with crop plants, followed a similar trend across growth stages. The pre-emergence application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} along with two intercultivation at 30 and 60 DAS recorded significantly lowest dry weight of total weeds (4.72, 3.78, 4.37 and 8.15 g, respectively). Conversely, the weedy check plot consistently exhibited significantly higher dry weight of total weeds per square meter (34.35, 42.92, 58.25 and 79.70 g respectively) compared to all other treatments.

This outcome can be attributed to the herbicidal efficacy of Metolachlor in controlling weed growth of diverse flora. The mode of action of herbicide involves inhibiting weed seedlings ability to establish a robust root and shoot system. This inhibition leads to a reduction in weed population during the initial stages of crop growth, particularly upto 30 DAS. Moreover, it is evident that treatment receives two intercultivation at 30 and 60 DAS after the pre-emergence herbicide application was likely disrupted weed growth and emergence. This disruption, initiated after 30 DAS, contributed

Table 1. Density of total weeds and dry weight of total weeds of sorghum at different growth stages as influenced by weed management treatments

Treatment	Total weed count per m²				Dry weight of total weeds (g m⁻²)			
	30 DAS	45 DAS	60 DAS	At harvest	30 DAS	45 DAS	60 DAS	At harvest
T_1: Atrazine 50WP @ 1000 g *a.i.*ha^{-1} as PE + two IC	2.41* (5.33)	2.11 (4.00)	1.68 (2.33)	1.86 (3.00)	2.44 (5.50)	2.16 (4.25)	2.37 (5.15)	3.10 (9.18)
T_2: Metribuzin 70WP @ 350 g *a.i.*ha^{-1} as PE + two IC	2.97 (8.33)	2.48 (5.67)	2.26 (4.67)	2.48 (5.67)	3.01 (8.59)	2.42 (5.39)	2.70 (6.78)	3.75 (13.70)
T_3: Metribuzin 70WP @ 700 g *a.i.*ha^{-1} as PE + two IC	2.48 (5.67)	2.27 (4.67)	1.87 (3.00)	2.11 (4.00)	2.54 (5.95)	2.35 (4.88)	2.36 (5.09)	3.46 (11.50)
T_4: Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC	2.86 (7.67)	2.34 (5.00)	1.87 (3.00)	2.03 (3.67)	2.91 (8.06)	2.32 (5.08)	2.49 (5.71)	3.31 (10.59)
T_5: Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as PE + two IC	2.26 (4.67)	1.94 (3.33)	1.46 (1.67)	1.68 (2.33)	2.27 (4.72)	2.03 (3.78)	2.21 (4.37)	2.94 (8.15)
T_6: Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PoE + one IC	5.82 (33.33)	2.85 (7.67)	2.53 (6.00)	2.60 (6.33)	5.89 (34.22)	3.22 (9.91)	3.15 (9.52)	4.30 (18.03)
T_7: Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PoE + one IC	5.87 (34.00)	2.60 (6.33)	2.41 (5.33)	2.47 (5.67)	5.93 (34.63)	2.98 (8.37)	2.90 (8.01)	4.06 (16.15)
T_8: Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC (RM) @ 550 g *a.i.* ha^{-1} asPoE + one IC	5.58 (30.67)	2.68 (6.67)	2.41 (5.33)	2.61 (6.33)	5.77 (32.81)	3.17 (9.59)	3.04 (8.72)	4.23 (17.41)
T_9: Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC (RM) @ 825 g *a.i.* ha^{-1} asPoE + one IC	5.72 (32.33)	2.54 (6.00)	2.27 (4.67)	2.40 (5.33)	5.82 (33.48)	2.92 (8.08)	2.93 (8.08)	3.93 (15.03)
T_{10}:Weed free check	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 (0.00)
T_{11}: Weedy check	.81 (33.33)	6.11 (37.00)	6.34 (39.67)	6.52 (42.00)	5.90 (34.35)	6.59 (42.92)	7.66 (58.25)	8.95 (79.70)
S.Em ±	0.12	0.12	0.11	0.14	0.15	0.14	0.13	0.18
C.D. (p = 0.05)	0.36	0.36	0.32	0.40	0.45	0.40	0.37	0.52

PE- Pre-emergence, PoE – Post-emergent (30 DAS), IC – Intercultivation (30 & 60 DAS), RM- Ready-mix, DAS – Days after sowing.
* Square root ($\sqrt{x+0.5}$) transformed values and the figures in parenthesis indicate the original values

to the subsequent reduction in weed population and weed biomass up to the harvest stage. The results were align with the findings of Solaimalai and Sivakumar (2002) and Ramakrishna (2003).

Weed control efficiency and weed index

The weed control efficiency (WCE) due to different weed management treatments varied significantly (Table 2). Among them, Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as PE + two IC at 30 and 60 DAS recorded significantly higher WCE of total weeds (86.01, 91.28, 92.50 and 89.74% at 30, 45, 60 DAS and harvest, respectively) and it was followed by Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC (83.78, 90.10, 91.16 and 88.01% at 30, 45, 60 DAS and harvest, respectively). This was primarily caused by decreased weed count and biomass as a result of the administration of integration of herbicides and two intercultivations at the appropriate growth stage. The similar finding corroborates with Sundari and Kathiresan (2002).

Table 2. Weed control efficiency of total weeds in sorghum at different growth stages as influenced by weed management treatments

Treatment details	WCE (%) of total weeds			
	30 DAS	45 DAS	60 DAS	At harvest
T_1: Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC	83.78	90.10	91.16	88.01
T_2: Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PE + two IC	74.86	87.40	88.35	83.12
T_3: Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC	82.72	88.65	89.53	85.50
T_4: Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC	76.53	88.21	89.27	86.60
T_5: Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as PE + two IC	86.01	91.28	92.50	89.74
T_6: Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PoE + one IC	-	76.88	83.71	78.32
T_7: Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PoE + one IC	-	80.51	86.24	80.10
T_8: Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC (RM) @ 550 g *a.i.* ha^{-1} asPoE + one IC	-	77.68	85.02	79.27
T_9: Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC (RM) @ 825 g *a.i.* ha^{-1} asPoE + one IC	-	81.09	86.12	81.49
T_{10}: Weed free check	100.00	100.00	100.00	100.00
T_{11}: Weedy check	-	-	-	-
S. Em ±	2.56	1.68	1.34	1.57
C. D. (p = 0.05)	8.07	4.99	3.98	4.68

Weed index (WI) is a measure of reduction in yield due to weed competition. In an extreme weed condition, when no yield was produced, then WI will be 100%. However, weed free check have WI value of zero (Table 3). Among rest of the treatments, lower weed index was observed in Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as PE + two IC at 30 and 60 DAS (7.21%) followed by Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC (11.62 %). This was because of less weed competition with the crop due to a decrease in weed count and dry weight, which may have allowed the crop to efficiently utilize natural resources including light, nutrients, moisture, and space, leading to enhanced growth and yield. Whereas, Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PoE + one IC at 60 DAS recorded higher WI (34.59%), since the weed infestation was greater as a result of less efficient weed control with a single dose of herbicide, which reduced grain yield.

Effect on crop

Data pertaining to the ear weight evaluated after harvest of *rabi* sorghum and results are given in Table 3. The results indicated that the weed-free treatment yielded a significantly higher ear weight of 59.03 g. However, it was found statistically similar to the treatments involving the application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as pre-emergence along with two intercultivation at 30 and 60 DAS (55.97), Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC (55.67), Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC (53.46), Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC (51.70) and Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PE + two IC (50.63). The lowest ear weight of 39.95 g was observed under the weedy check treatment.

The results revealed that significantly higher grain weight per ear (43.64 g) was obtained in the weed free treatment, however it was found statistically on par with application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as PE + two IC at 30 and 60 DAS (41.75 g), Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC (40.21 g), Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC (39.56 g), Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC (39.14 g) and Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PE + two IC (38.58 g). Minimum ear weight of 28.56 g was recorded under treatment weedy check. This could be attributed to reduced weed competition in treatments with effective control during the initial days and the later phases of crop development. The effective weed control linked to better growth of crop in terms of higher leaf area index and dry matter production in these treatments, which may have resulted in better translocation of photosynthates for development of all the yield attributes. These results are in close conformity with the findings of Sundari and Kathiresan (2002), Solaimalai and Sivakumar (2002) and Ramakrishna (2003).

The grain yield of sorghum was significantly higher in the weed free treatment compared to other treatment. However which was on par with application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as PE + two IC at 30 and 60 DAS (1389 kg ha^{-1}) , Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC (1328 kg ha^{-1}), Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC (1311 kg ha^{-1}), Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC (1295 kg ha^{-1}) and Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PE + two IC (1276 kg ha^{-1}). The higher yield in these treatments might be due to more effective weed control at crucial growth stages, leading to reduced weed count, lower weed biomass, and higher weed control efficiency. Additionally, higher values yield related characteristics *viz*., ear weight, grain weight per ear, and test weight observed in these treatments may have also played a role in enhancing grain yield. While, weedy check recorded significantly the lowest grain yield among all the treatments. There was 70 per cent yield reduction observed in weedy check treatment compared to weed free condition. Which might be due to competition faced the crop by weeds for nutrients, moisture light, space etc.,. The results were conformity with the findings of Solaimalai and Sivakumar (2002), Sundari and Kathiresan (2002), Ramakrishna (2003) and Bararpour *et al*. (2019).

Like grain yield the stover yield of sorghum was also the highest in the weed free treatment and which was statistically on par with treatments, Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as PE + two IC at 30 and 60 DAS (3031 kg ha^{-1}), Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC (2889 kg ha^{-1}), Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC (2774 kg ha^{-1}), Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC (2724 kg ha^{-1}) and Metribuzin

Table 3. Yield attributes, grain yield and stover yield as influenced by different weed management treatments

Treatment details	Ear weight (g)	Grain weight per ear (g)	Grain yield (kg ha^{-1})	Stoveryield (kg ha^{-1})	Weed index(%)
T_1: Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC	55.67	40.21	1328	2889	11.62
T_2: Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PE + two IC	50.63	38.58	1276	2695	13.25
T_3: Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC	51.70	39.14	1295	2724	13.75
T_4: Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC	53.46	39.56	1311	2774	12.52
T_5: Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as PE + two IC	55.97	41.75	1389	3031	7.21
T_6: Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PoE + one IC	48.33	35.48	978	2057	34.59
T_7: Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PoE + one IC	49.87	36.85	1028	2246	31.52
T_8: Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC (RM) @ 550 g *a.i.* ha^{-1} asPoE + one IC	48.33	35.80	1039	2294	30.56
T_9: Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC (RM) @ 825 g *a.i.* ha^{-1} asPoE + one IC	50.19	37.20	1098	2480	26.12
T_{10}: Weed free check	59.03	43.64	1496	3102	0.00
T_{11}: Weedy check	39.95	28.56	449	1027	69.95
S.Em ±	2.99	2.02	78	157	1.65
C. D. (p = 0.05)	8.77	5.93	230	461	4.83

Table 4. Effect of different weed management treatments on economics of sorghum

Treatment details	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	BCR
T_1: Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC	31491	70456	38565	2.24
T_2: Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PE + two IC	31441	67404	35784	2.14
T_3: Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC	32391	68133	35742	2.10
T_4: Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC	31641	69069	37428	2.18
T_5: Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as PE + two IC	32791	73759	40968	2.25
T_6: Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PoE + one IC	29441	51447	22006	1.75
T_7: Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PoE + one IC	30391	54581	24190	1.80
T_8: Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC (RM) @ 550 g *a.i.* ha^{-1} asPoE + one IC	30481	55313	24832	1.81
T_9: Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC (RM) @ 825 g *a.i.* ha^{-1} asPoE + one IC	31441	58798	27357	1.87
T_{10}: Weed free check	33591	78437	44846	2.34
T_{11}: Weedy check	25491	24109	-1382	0.95
S.Em ±	-	3577	3577	0.11
C.D. (p = 0.05)	-	10493	10493	0.34

70WP @ 350 g *a.i.* ha^{-1} as PE + two IC (2695 kg ha^{-1}). There was 66 per cent higher stover yield was observed in weed free treatment compared to unweeded treatment. The results were conformity with the findings of Sundari and Kathiresan (2002), Solaimalai and Sivakumar (2002), Ramakrishna (2003) and Bararpour *et al*. (2019).

Economics

Among the treatments, the lowest cost of cultivation was associated with weedy check (₹ 25,491 ha^{-1}) followed by Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PoE + one IC (₹ 29,441 ha^{-1}) (Table 4). Meanwhile, weed free check recorded the highest cost of cultivation (₹ 33,591 ha^{-1}) followed by application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as PE + two IC (₹ 32,791 ha^{-1}), Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC (₹ 32,391 ha^{-1}) and Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC (₹ 31,641 ha^{-1}).

Significantly higher gross returns was observed with weed free check (₹ 78,437 ha^{-1}), however, it was found to be on par with application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as pre-emergence along with two intercultivation at 30 and 60 DAS (₹ 73,759 ha^{-1}), Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC (₹ 70,456 ha^{-1}) and Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC (₹ 69,069 ha^{-1}) and Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC (₹ 68,133 ha^{-1}). Significantly lower gross returns were noticed in weedy check (₹ 24,109 ha^{-1}) compared to rest of the treatments. The higher gross returns of these treatments were attributed to higher seed yield which was due to higher weed control efficiency and lower weed index.

Among all the treatments significantly higher net returns were noticed with weed free check (₹ 44,846 ha^{-1}) as compared to other treatments and it was on par with application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as pre-emergence along with two intercultivation at 30 and 60 DAS (₹ 40,968 ha^{-1}), Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC(₹ 38,565 ha^{-1}), Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC (₹ 37,428 ha^{-1}), Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC (₹ 35,742 ha^{-1}) and Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PE + two IC (₹ 35,784 ha^{-1}). This was because of higher gross returns which are in turn governed by higher economic yield and fetching better market price. Among the other treatments, weedy check recorded the lowest net returns (₹ - 1382). These findings align with the results of Rao *et al*. (2007), Kumar *et al*. (2012), Priya and Kubsad (2013) and Vinayaka *et al.*(2020).

The treatment with the highest BCR (2.35) was weed-free check, which outperformed the other treatments. However, it was on par with application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} as pre-emergence along with two intercultivation at 30 and 60 DAS (2.25), Atrazine 50WP @ 1000 g *a.i.* ha^{-1} as PE + two IC (2.24), Metolachlor 50EC @ 750 g *a.i.* ha^{-1} as PE + two IC (2.18), Metribuzin 70WP @ 700 g *a.i.* ha^{-1} as PE + two IC (2.10) and Metribuzin 70WP @ 350 g *a.i.* ha^{-1} as PE + two IC (2.14). In contrast, weedy check recorded significantly lower BC ratio (0.95) compared to all other treatments.

Conclusion

Based on the results of the experimentation for effective management of weeds in *rabi* sorghum, pre-emergence application of Metolachlor 50EC @ 1500 g *a.i.* ha^{-1} along with two intercultivations at 30 and 60 DAS resulted in better weed control, higher yield (1389 kg ha^{-1}), net returns (₹ 40,968 ha^{-1}) and BCR (2.25). Thus, it may be recommended for effective weed control in *rabi* sorghum.

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