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Weed Management Practices on Growth, Yield and Economics of *Kharif* Grain Sorghum

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In the *Kharif* grain sorghum growing areas of Karnataka, the sorghum production suffers greatly due to weed problem, which offers limitations to crop. It was found that weed infestation become unmanageable throughout the growing period by the traditional methods of interculturing and manual weeding due to continuous and heavy rains during entire vegetative and early reproductive stages of *Kharif* sorghum. Hence, integration of herbicides with some cultural operations and use of pre-emergence, post-emergence herbicides in combination with mechanical methods can prove to be more successful. A field experiment entitled "Weed management in *kharif* grain sorghum" was

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conducted during *Kharif* 2019 at ARS, Hagari in deep black soil with neutral reaction (pH 7.50), organic carbon (5.5 g kg^{-1}), available nitrogen (248.00 kg ha^{-1}), available phosphorus (36.75 kg ha^{-1}) and available potassium (312.00 kg ha^{-1}). An experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. There were fourteen treatments comprising of weed management practices. The dominant weeds observed in the experimental fields were among grasses *Brachiaria reptans,* while in broad leaved weeds, *Amaranthus viridis* and among sedges, *Cyperus rotundus*. Significantly lower population 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} as PE *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as PoE at 25 DAS except weed free treatment. Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as PoE at 25 DAS recorded significantly higher plant height, dry matter accumulation, leaf area, test weight, grain yield, straw yield, harvest index, gross return, net return and benefit cost ratio (160.8 cm, 183.4 $gplant^{-1}$, 24.1 dm^2 $plant^{-1}$, 30.53 g, 4195 kg ha^{-1}, 9891 kg ha^{-1}, 29.80 %, Rs. 1,03,675ha^{-1}, Rs. 71,636 $ha^{-1}$and 3.24, respectively**)** except weed free and it was on par with atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* IC at 25 DAS and HW at 25 DAS and IC at 40 DAS.

Keywords: Weed dynamics; weeds dryweight; kharif grain sorghum; weed management practices and yield.

1. INTRODUCTION

"Sorghum [*Sorghum bicolor* (L.)] is an important staple food crop in the world; it is the fifth most important cereal crop after wheat, rice, maize and barley. Sorghum is a unique crop among the major cereals and the staple food and fodder crop of the world's poor and most food-insecure populations, located primarily in the semi-arid tropics. It is one of the major cereal crops consumed in India after rice and wheat. It is considered as king of millets and it extensively grown in semi-arid tracks of Africa, China and India. Sorghum is grown on 42 million ha area in the world, producing about 57.46 m t of grain with an average yield of 1368 $kgha^{-1}$. Sudan and India have largest share of global sorghum area, while the maximum production of sorghum occurs in the United States and Nigeria" [1]. "India presently produces about 4.95 million tonnes of sorghum grain from an area of 4.96 m ha with a productivity of 998 kg ha^{-1}" [2]. "The crop is primarily produced in Maharashtra, Andhra Pradesh, Gujarat and Karnataka. In Karnataka, sorghum occupies about 1.09 m ha area with annual production of 1.13 m t with a productivity of 1040 $kgha^{-1}$" [2]. Sorghum grain contains 11.3% protein, 3.3% fat and 56.73% starch. It is relatively rich in iron, zinc, phosphorus and vitamin B complex. Tannins are found particularly in red-grain types, contain antioxidants that protect against cell damage, a major cause of diseases and aging. The protein and starch in sorghum grain are more slowly digested than those from other cereals and slower rates of digestibility are particularly beneficial for people with diabetes. In Karnataka, sorghum is mainly grown in Belgaum, Vijayapura, Bagalkot, Dharwad, Ballari and Gadag districts both in *kharif* and *rabi* seasons. 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.

The wide space provided to the sorghum, allows fast growth of a variety of weed species causing a considerable reduction in yield by affecting the growth and yield components. The presence of weeds reduces the photosynthetic efficiency, dry matter production and distribution to economical parts and thereby reduces sink capacity of crop resulting in poor grain yield. Unlike other pests, weeds are ubiquitous and affect almost all the crops. Presence of weeds in general reduces crop yields by 37%.

"Based on survey conducted in the *kharif* sorghum growing areas of Karnataka, the sorghum production suffers greatly due to weeds problem, which offers limitations to crop. It was found that weed infestation become unmanageable throughout the growing period by the traditional methods of interculturing and manual weeding due to continuous and heavy rains during entire vegetative and early reproductive stages of *kharif* sorghum. The traditional methods of inter-culturing and manual weeding are more effective in controlling weeds, but are tedious and time consuming besides labor intensive and costly. Often these

operations are difficult to carry out in the field owing to excess soil moisture due to heavy and continuous *kharif* rains. Under such situations weed control becomes very difficult either by hand weeding or by intercultivation. The major problem is further aggravated because of severe labour scarcity to control weeds effectively at critical time. However, chemical method of weed control has become efficient and time saving with the introduction of herbicides. This is particularly true under intensive crop production practices. Usage 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. As the weeds interfere during the harvesting of the crop, post-emergence herbicides at about 35 DAS may help in avoiding the problem of weeds at later stages. The integration of herbicides with some cultural operations and use of pre-emergence, post-emergence herbicides in combination with mechanical methods can prove to be more successful. Thus, integrated weed management is gaining importance in management of weeds by preventing losses and higher input-use efficiency" (Ishaya et al. [3]). Keeping in view the above facts, the present investigation was carried out to study the "Weed dynamics, growth, yield and economics of *kharif* grain sorghum as influenced by various weed management practices" at Agricultural Research Station, Hagari, Ballari.

2. MATERIALS AND METHODS

A field experiment was conducted during *kharif* 2019 at Agricultural Research Station, Hagari, Ballari and it is located on 15o 14' N latitude and 77o 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). The soil of the experimental field was clayey in texture. The soil's available nutrient status showed low availability of nitrogen (248.00 kg ha^{-1}), medium in available phosphorus (36.75 kg ha^{-1}) and high in available potassium (312.00 kg ha^{-1}). The organic carbon content was medium (5.5 g kg^{-1}). Fourteen 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* one IC at 25 DAS, T3 : T1 fb 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha-1 as PoE at 25 DAS, T_4 : T_1 *fb* Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS, T_5 : T_1 *fb* Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS, T_6 : T_1 *fb* Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS, T_7 : T_1 *fb* Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS, T_8 : T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS, T_9 : T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS, T_{10} :T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS, T_{11}: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS, T_{12} : HW at 25 DAS and one IC at 40 DAS, T_{13}: Weed free (IC at 25 & 40 DAS and HW at 30 DAS) and T_{14}: 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 urea, diammonium phosphate (DAP) and Muriate of potash, respectively and these were band placed at the time of sowing and remaining 50 % nitrogen was applied at 4 weeks after sowing|". [4] 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 (5.5 g kg^{-1}), available nitrogen (248 kg ha^{-1}), available phosphorous (36.75 kg ha^{-1}) and available potassium (312.0 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. Further, application of herbicides were done at different stages among different herbicides atrazine 50 WP @ 1.0 kg ha^{-1} was applied as pre-emergent at the time of sowing while other herbicides like 2,4-D Na Salt 80 WP@ 0.94 kg ha^{-1}, Topramezome 33.6 SC @ 37.5 ml ha^{-1}, Tembotrione 34.4 SC @ 70 ml ha^{-1}, Topramezome 33.6 SC @ 56.25 ml ha^{-1}, Tembotrione 34.4 SC @ 105 ml ha^{-1}, as PoE at 25 DAS and their mixtures were applied as post-emergent after 25 days after sowing. Inter cultivation was done at 25 and 40 days after sowing, while hand weeding was done at 30 days after sowing.

Data on weed dry weight (g m^{-2}) was recorded at 20, 40 and 60 days after sowing (DAS) at three

spots per plot and weed control efficiency (WCE) was worked out taking weed dry weight into consideration. Further, data on dry weight was subjected to square root transformation ($\sqrt{x+0.25}$) before analysis. The field experiment was laid out in Randomized Complete 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). Data on growth attributes were recorded from five randomly selected plants, whereas yield attributes and yield data were recorded from net plots at harvest. For economic study prevailing market price was used for different outputs and inputs.

2.1 Statistical Analysis

All the parameters were subjected for statistical analysis and interpretation as outlined by Panse and Sukhatme [5]).

3. RESULTS AND DISCUSSION

3.1 Weed Attributes

During the course of study prominent weed species in the experimental plot were *Cynodon dactylon, Brachiaria reptans, Chloris inflata, Dactyloctenium aegeptium, Brachiaria eruciformis, Dinebra retroflexa* and *Cynotis culcullata* among grassy weeds; *Euphorbia geniculata, Abutilon hirtum, Amaranthus viridis, Aristolachia bractiata, Euphorbia humifusa* and *Digera muricate* among the broad leaf weeds and *Cyperus rotundus* was the only sedge. Similar weed flora was reported by Thakur et al. [6] at Indore and Sreeram et al. [7] at Bapatla.

Total dry weight of weeds at 60 DAS and at harvest, was significantly lower with Pre-emergence application of atrazine 50 WP @ 0.50 kg a.i. ha^{-1} *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as Post-emergence at 25 DAS (22.93 and 35.43 g m^{-2}, respectively) and it was on par with Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* one IC at 25 DAS (25.04 and 37.00 g m^{-2}) and HW at 25 DAS and one IC at 40 DAS (26.29 and 39.11 g m^{-2}). Total dry weight of weeds was significantly higher with weedy check (133.22 and 238.25 g m^{-2}) over other treatments (Table 1). These results are conformity with findings of Grima and Chinawong [8], Ramesh and Nadanassababady [9] and Vinayaka et al. [10].

Weed control efficiency at 60 DAS and at harvest was lower with weedy check (0.00 and 0.00%, respectively) (Table 2) over all other treatments. Weed control efficiency was significantly higher with Atrazine 50 WP @ 0.50 kg active ingredient ha^{-1} as PE *fb* post emergence application of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} (82.78 and 85.12 %, respectively) and it was on par with Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE fb one IC at 25 DAS (81.20 and 84.47 %) followed by HW at 25 DAS and one IC at 40 DAS (80.26 and 83.58 %). These results are in corroborate with the findings of Agrawal et al. [11], Patel et al. [12], Priya and Kubsad [13], Shantveerayya et al. [14] and Vinayaka et al. [15].

3.2 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). 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. [15] and Vinayaka et al. [16]. were obtained similar results in sorghum.

3.3 Growth Attributes

Among different growth parameters significantly taller plants and leaf area, was higher in case of weed free check. Whereas among different herbicidal treatments Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as PoE at 25 DAS produced higher plant height and leaf area, at harvest (158.6cm, and 31.3 dm^2 $plant^{-1}$) these results were on par with atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* one IC at 25 DAS and HW at 25 DAS and one IC at 40 DAS (Table 4). This was mainly because of sufficient nutrient and moisture availability to the sorghum crop plants in absence of weeds and also less competition consequently crop plants get better environment for growth,

Table 1. Total dry weight of weeds at different growth stages of *kharif* grain sorghum as influenced by 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	3.19 (9.97)	4.91 (23.92)	5.99 (35.79)
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* one IC at 25 DAS	3.05 (9.09)	4.49 (19.93)	5.01 (25.04)
T_3 : T_1 *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as PoE at 25 DAS	3.07 (9.17)	4.33 (18.62)	4.81 (22.93)
T_4 : T_1 *fb* Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS	3.83 (14.39)	5.73 (32.69)	7.57 (57.06)
T_5 : T_1 *fb*Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS	3.66 (13.29)	5.00 (24.73)	6.44 (41.28)
T_6 : T_1 *fb* Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS	4.38 (18.94)	5.88 (34.44)	7.74 (59.69)
T_7 : T_1 *fb* Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS	3.60 (12.68)	5.60 (31.08)	6.44 (41.29)
T_8 : T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS	3.66 (13.55)	5.80 (33.45)	6.91 (47.55)
T_9 : T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS	4.33 (18.49)	5.72 (32.44)	6.81 (45.64)
T_{10} :T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS	3.91 (15.07)	5.84 (33.85)	7.43 (55.03)
T_{11}: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS	4.07 (16.30)	5.81 (33.52)	6.92 (47.67)
T_{12} : HW at 25 DAS and one IC at 40 DAS	5.32 (28.20)	4.57 (20.71)	5.15 (26.29)
T_{13}: Weed free (IC at 25 & 40 DAS and HW at 30 DAS)	5.45 (29.42)	4.01 (15.91)	4.59 (20.86)
T_{14}: Weedy check	5.95 (35.16)	8.91 (79.20)	11.55 (133.22)
S. Em±	**0.11**	**0.16**	**0.22**
C.D. (P=0.05)	**0.34**	**0.50**	**0.67**

** 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* ***SC****: Soluble concentrates* ***PoE:*** *Post emergence* ***HW:*** *Hand Weeding*

Table 2. Weed control efficiency at different growth stages of *kharif* grain sorghum as influenced by 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	71.64	69.79	73.13
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* one IC at 25 DAS	74.14	74.83	81.20
T_3 : T_1 *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as PoE at 25 DAS	73.91	76.48	82.78
T_4 : T_1 *fb* Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS	59.07	58.72	57.16
T_5 : T_1 *fb*Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS	62.20	68.77	69.01
T_6 : T_1 *fb* Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS	46.13	56.51	55.19
T_7 : T_1 *fb* Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS	63.93	60.75	69.00
T_8 : T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS	61.46	57.76	64.30
T_9 : T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS	47.41	59.04	65.74
T_{10} :T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS	57.13	48.40	58.69
T_{11}: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS	53.64	57.26	64.23
T_{12} : HW at 25 DAS and one IC at 40 DAS	19.79	73.85	80.26
T_{13}: Weed free (IC at 25 & 40 DAS and HW at 30 DAS)	16.32	79.91	84.34
T_{14}: Weedy check	0.00	0.00	0.00
S. Em±	**1.68**	**1.77**	**1.89**
C.D. (P=0.05)	**5.11**	**5.37**	**5.75**

** 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* ***SC****: Soluble concentrates* ***PoE:*** *Post emergence* ***HW:*** *Hand Weeding*

Table 3. Germination percentage, plant height and number of branches per plant of succeeding chickpea at 45 DAS as influenced by different weed management practices in *kharif* sorghum

Treatments	Germination (%)	Plant height (cm)	Number of branches plant^{-1}
T_1 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE	89	18.8	3.3
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* one IC at 25 DAS	90	19.4	3.3
T_3 : T_1 *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as PoE at 25 DAS	91	20.2	3.7
T_4 : T_1 *fb* Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS	87	18.5	3.3
T_5 : T_1 *fb*Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS	87	18.7	3.7
T_6 : T_1 *fb* Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS	87	18.2	3.8
T_7 : T_1 *fb* Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS	88	18.7	3.6
T_8 : T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS	88	18.6	3.7
T_9 : T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS	87	18.4	3.3
T_{10}: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS	86	18.5	3.0
T_{11}: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS	89	18.9	3.3
T_{12} : HW at 25 DAS and one IC at 40 DAS	90	19.0	3.3
T_{13}: Weed free (IC at 25 & 40 DAS and HW at 30 DAS)	90	20.7	4.0
T_{14}: Weedy check	86	17.5	3.0
S. Em±	**1.1**	**0.6**	**0.4**
C.D. (P=0.05)	**NS**	**NS**	**NS**

** Figures in parentheses indicate original values* *Transformation- (√X+0.25)* ***WP:*** *Wettable powder* ***PE:*** *Pre-emergence* ***fb:*** *Followed by*
IC: *Inter cultivation* ***DAS:*** *Days after sowing* ***SC****: Soluble concentrates* ***PoE:*** *Post emergence* ***HW:*** *Hand Weeding*

Table 4. Plant height, leaf area, Grain yield, straw yield, harvest index at harvest of kharif sorghum as influenced by different weed management practices

Treatments	Plant height (cm)	Leaf area (dm^2 $plant^{-1}$)	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	156.9	156.9	3600	8952	28.5
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* one IC at 25 DAS	160.0	160.0	4088	9786	29.5
T_3 : T_1 *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as PoE at 25 DAS	160.8	160.8	4195	9891	29.8
T_4 : T_1 *fb* Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS	154.1	154.1	2272	6038	27.3
T_5 : T_1 *fb*Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS	156.1	156.1	3026	7928	27.7
T_6 : T_1 *fb* Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS	152.6	152.6	2190	5601	28.1
T_7 : T_1 *fb* Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS	156.5	156.5	2728	7505	26.8
T_8: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS	154.5	154.5	2213	5811	27.6
T_9: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS	154.9	154.9	2448	6902	26.2
T_{10}: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS	149.5	149.5	2086	5390	28.1
T_{11}: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS	156.1	156.1	2403	6281	27.7
T_{12} : HW at 25 DAS and one IC at 40 DAS	159.6	159.6	3946	9658	29.0
T_{13}: Weed free (IC at 25 & 40 DAS and HW at 30 DAS)	161.5	161.5	4233	10031	29.7
T_{14}: Weedy check	141.2	141.2	1343	4662	22.4
S.Em±	**1.2**	**1.2**	**140**	**260**	**1.2**
C.D. (P=0.05)	**3.7**	**3.7**	**424**	**790**	**NS**

** 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* ***SC****: Soluble concentrates* ***PoE:*** *Post emergence* ***HW:*** *Hand Weeding*

Table 5. Economics of *kharif* grain sorghum cultivation as influenced by different weed management practices

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	Benefit cost ratio
T_1 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE	30815	89905	59089	2.91
T_2 : Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* one IC at 25 DAS	32232	101339	69106	3.14
T_3 : T_1 *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as PoE at 25 DAS	32039	103675	71636	3.24
T_4 : T_1 *fb* Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS	32580	57516	24936	1.77
T_5 : T_1 *fb*Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS	32089	76370	44281	2.38
T_6 : T_1 *fb* Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS	33553	54996	21443	1.64
T_7 : T_1 *fb* Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS	32357	69569	37212	2.15
T_8: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0126 kg a.i. ha^{-1} as PoE at 25 DAS	32895	55889	22994	1.70
T_9: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0242 kg a.i. ha^{-1} as PoE at 25 DAS	32092	62770	30678	1.96
T_{10}: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Topramezome 33.6 SC @ 0.0189 kg a.i. ha^{-1} as PoE at 25 DAS	33840	52493	18653	1.55
T_{11}: T_1 *fb* Tank mix of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} + Tembotrione 34.4 SC @ 0.0363 kg a.i. ha^{-1} as PoE at 25 DAS	32512	60629	28117	1.86
T_{12} : HW at 25 DAS and one IC at 40 DAS	36885	98243	61358	2.66
T_{13}: Weed free (IC at 25 & 40 DAS and HW at 30 DAS)	37834	104715	66881	2.77
T_{14}: Weedy check	28337	36177	7840	1.28
S.Em±	**84**	**2810**	**2727**	**0.08**
C.D. (P=0.05)	**254**	**8523**	**8274**	**0.25**

** Figures in parentheses indicate original values* *Transformation- (√X+0.25)* ***WP:*** *Wettable powder* ***PE:*** *Pre-emergence* ***fb:*** *Followed by*
IC: *Inter cultivation* ***DAS:*** *Days after sowing* ***SC****: Soluble concentrates* ***PoE:*** *Post emergence* ***HW:*** *Hand Weeding*

ultimately increased all the growth parameters. Weedy check produced lower plant growth parameters was mainly because of severe competition among the weeds for essential moisture and nutrients and weeds create smothering effect on crop which restricted the availability of sunlight to germinating crop plant consequently the plant growth was affected this resulted in decreased plant growth parameters. These results were similar with findings of Kannur [17], Shakoor et al. [18] and Vinayaka et al. [10].

3.4 Yield and yield Attributes

Grain and stover yield were significantly higher in weed free check (IC at 25 & 40 DAS and HW at 30 DAS) (4233 kg ha^{-1} and 10031 kg ha^{-1}) and significantly lower grain yield was recorded in weedy check (1343 kg ha^{-1} and 4662 kg ha^{-1}). Among other weed management treatments, grain yield and stover yield was significantly higher with atrazine 50 WP @ 0.50 kg active ingredient ha^{-1} as PE *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as post emergence at 25 DAS recorded significantly0higher grain yield (4195 kg ha^{-1} and 9891 kg ha^{-1}) and it was0on par with atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* one IC at 25 DAS (4088 kg ha^{-1} and 9786 kg ha^{-1}) and HW at 25 DAS and one IC at 40 DAS (3946 kg ha^{-1} 9658 kg ha^{-1}) (Table 4). Better results in above treatments are due to control of broad spectrum of weeds effectively during the critical crop weed competition period, which otherwise were quite notorious for imposing competition for light, space and nutrients with crop. It has provided congenial environment for better expression of growth stature and yield attributes *viz*., ear head length, number of grains per ear head, test weight and grain weight per ear head. The cumulative effect of all these yield components resulted in increased grain yield. Priya and Kubsad [13], Shakoor et al. [18], Verma et al. [19] and Vinayaka et al. [10] were obtained similar results in sorghum.

Further different yield parameters such as length of ear head (cm), grain weight per ear head (g), test weight (g 1000 $grains^{-1}$) contributed significantly towards the yield, among different herbicidal treatments atrazine 50 WP @ 0.50 kg active ingredient ha^{-1} as PE *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as post emergence at 25 DAS recorded significantly higher length of ear head, number of grains per ear head, grain weight per ear head, test weight and it on par with atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE *fb* one IC at 25 DAS and HW at 25 DAS and one IC at 40 DAS. This may be because of lesser weeds were observed in these treatments, which may have resulted in increased nutrient, water, space and light supply to sorghum crop due to absence of crop-weed competition and ultimately higher value of yield attributes. Shivamurugan et al. [20], Kannur [17], Shakoor et al. [18] and Vinayaka et al. [10] reported similar findings.

3.5 ECONOMICS

Among different herbicidal treatments atrazine 50 WP @ 0.50 kg a.i.ha^{-1} as PE *fb* 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} as post emergence at 25 DAS produced significantly higher gross returns, net returns and B:C ratio (103,675 ha^{-1}, 71,636 ha^{-1} and 3.24 respectively) (Table 5). This is due to higher gross returns and lower cost of cultivate on obtained from these treatments. The results are in confirmatory with the findings of Sreenivas and Satyanarayana [21], Priya and Kubsad [13], Ramarao et al. [22], Satyendra et al. [23] and Vinayaka et al. [10].

4. CONCLUSION

It was concluded that Pre-emergence application of atrazine 50 WP @ 0.50 kg a.i. ha^{-1} followed by post emergence application of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} at 25 DAS was recorded significantly higher grain yield, stover yield, net returns and benefit-cost ratio. Pre-emergence application of atrazine 50 WP @ 0.50 kg a.i. ha^{-1} followed by post emergence application of 2,4-D Na Salt 80 WP @ 0.75 kg a.i. ha^{-1} at 25 DAS and Atrazine 50 WP @ 0.50 kg a.i. ha^{-1} as PE followed by one inter cultivation at 25 DAS was found beneficial and recorded significantly lower weed dry weight and higher weed control efficiency.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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