Effect of different weed management practices on growth, yield and economics of *kharif* grain sorghum [*Sorghum bicolor* (L.) Moench]

ABSTRACT

A field experiment was conducted during the *kharif* season of 2023 at the Agricultural Research Station in Hagari, Ballari, to assess the effect of different weed management practices on the growth and yield of *kharif* grain sorghum. The experiment was replicated thrice in randomized complete block design comprising of eleven different treatments. According to the findings, the growth parameters like plant height (138.8 cm), number of leaves per plant (8.9), leaf area (29.1 dm^2 $plant^{-1}$), leaf area index (4.31) and total dry matter production (212.3 g $plant^{-1}$) at harvest recorded significantly higher with the application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS (T_7) treatment. This treatment also recorded higher grain yield (2905 kg ha^{-1}), stover yield (8576 kg ha^{-1}), harvest index (25.3%), gross returns (Rs. 1,19,425 ha^{-1}), net returns (Rs. 80,988 ha^{-1}) and B:C (3.11) when compared with other treatments. Which might be due to, application of atrazine as pre-emergent control weeds in earlier stages of crop and post-emergent application of metribuzin control weeds in later stages of crop growth. The application of atrazine and metribuzin helps in better growth of plant and obtaining the higher grain yield, net returns and B:C found economically feasible.

Keywords: Sorghum; pre-emergent; post-emergent; growth; yield.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* L.) is a self-pollinated C_4 grass with a high photosynthetic efficiency, belongs to the grass family Poaceae and is an important staple food crop in the world, it is the fifth most important cereal crop after wheat, rice, maize and barley. It's commonly called sorghum and also known as great millet, broomcorn, guinea corn, durra, imphee, jowar or milo is a grass species cultivated for its grain, which is used for food for humans, animal feed and ethanol production. Sorghum (King of millets) originated in Africa and is now cultivated widely in tropical and subtropical regions. Sorghum is called "the camel of crops" it has earned this name because of its ability to grow in arid soils and withstand prolonged droughts.

Sorghum is one of the major cereal crop consumed in India after rice and wheat. In India the area and production of sorghum during 2023-24 was 4.1 m ha and 4.4 m t respectively, with productivity of 1073 kg ha^{-1} (Anon., 2024)[1]. The crop is primarily produced in Maharashtra, Andhra Pradesh and Northern districts of Karnataka. India is the fourth largest producer of sorghum in the world after United States, Nigeria and Ethiopia Shahbandeh, 2022[2]. In Karnataka, sorghum is mainly grown in Belagavi, Bijapur, Bagalkot, Dharwad, Haveri and Gadag districts both in *kharif* and *rabi* seasons. Karnataka is the second largest sorghum producer in India, after Maharashtra. In Karnataka the area and production of sorghum during 2022-23 was 0.75 m ha and 0.903 m t respectively, with productivity of 1205 kg ha^{-1} (Anon., 2023)[3].

Weeds are one of the major problems in limiting the productivity of *kharif* sorghum. Weed management in rainfed sorghum is an important aspect to check the nutrient, water loss and to increase the grain and fodder yield. Weed control is indispensable in modern crop management because weeds cause competition for light, moisture, space, nutrients and may have some allelopathic effects as well, resulting in poor crop growth and thereby yield is reduced markedly. Weed competition in grain sorghum reduces yield, causes harvesting losses and increases weed seed content of the soil seed bank. 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. Thus, the extent of reduction of yield losses ranging from 40-80% had been attributed to weed competition during the growth of the sorghum Lagoke *et al*., 1990[4]. Mishra, 1997[5] reported 15-40 per cent loss in grain yield due to weed competition in sorghum. It is well established that 30 to 60 DAS is the most critical period for crop-weed competition in sorghum. Hence, managing weeds during this period is most critical for getting higher yields. Clean and weed free cultivation is, therefore one of the principles of modern days farming agriculture.

Usage of pre-emergence herbicides assumes greater importance in the view of their effectiveness from initial stages. As the weeds interfere during the harvesting of the crop, post-emergence herbicides at about 25 DAS may help in avoiding the problem of weeds at later stages. Under such situation, managing weeds through pre-emergence, post-emergence and sequential use of herbicides will be an ideal means of controlling the weeds for enhancing productivity of *kharif* sorghum.

2. MATERIALS AND METHODS

An experiment was conducted at Agricultural Research Station, Hagari, which is situated at 15° 13' N latitude and 77° 05' E longitude with an altitude of 414 meters above the mean sea level and is located in Northern Dry Zone of Karnataka (Zone-III) during *kharif* 2023 with the objective to study the effect of different weed management practices on growth and yield of *kharif* grain sorghum and to work out the economics of different weed management practices in *kharif* grain sorghum. The soil was medium black with a neutral pH of 7.6, low in EC of 0.53 dS m^{-1} and medium in organic carbon content 5.3 g kg^{-1}. The available nitrogen, phosphorus, and potassium levels were reported as 252.8 kg ha^{-1}, 40.9 kg ha^{-1} and 327.1 kg ha^{-1}, respectively (Subbiah and Asija, 1956[6], Olsen *et al*., 1954 [7], Jackson, 1973[8].

The study was conducted with CSH-16 hybrid at spacing 45 cm x 15 cm and the crop was fertilized with RDF of FYM (5 t ha^{-1}), NPK and Zn (100:75:37.5:15) kg ha^{-1} through urea, DAP, MOP and zinc sulphate. Nitrogen application was made in two splits, 50 per cent at the time of sowing and remaining 50 per cent was top dressed at 30 DAS (days after sowing). Entire quantities of P, K and Zn were applied as basal dose at the time of sowing. A field experiment comprised of eleven treatments of which eight treatments are with herbicides, two treatments based on hand weeding and intercultivation and one weedy check *viz.* atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS (T_1), metribuzin70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS (T_2), pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS (T_3), atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (T_4), metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (T_5), pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (T_6), atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS (T_7), atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PoE at 15-18 DAS (T_8), farmers' practice (One HW at 25 DAS and two IC at 15 & 30 DAS) (T_9), weed free check (T_{10}) and weedy check (T_{11}). The experiment was laid out in complete randomized block design with three replications with gross plot size of 4.5 m x 5.1 m and net plot size of 2.7 m x 4.5 m. Herbicide application was done using a backpack knapsack sprayer equipped with a flat fan nozzle. Spray volume of 750 L ha^{-1} was used for pre-emergent herbicides, while 500 L ha^{-1} spray volume for post-emergent herbicides.

Growth parameters five plants from sampling area were randomly selected and tagged. Observations on the various growth parameters (plant height, number of leaves per plant, leaf area per plant, leaf area index and dry matter production of plant) were recorded at 30, 60, 90 and at harvest. The earhead from the five plants selected for taking growth observations at the time of harvest were used for recording following observations on yield components like length of the earhead, grain number per earhead, grain weight per plant, test weight. Yield parameters like grain yield, stover yield and harvest index was recorded after harvest of crop. The cost of inputs, labour charges and prevailing market rates of farm produce were taken into consideration for working out cost of cultivation, gross returns and net returns per hectare and B:C.

2.1 Statistical Analysis

The analysis and interpretation of data were done using the Fisher's method of analysis and variance technique as given by Panse and Sukhatme, 1967[9]. The level of significance used in "F" and "t" test was at 5% probability level and wherever "F" test was found significant, the "t" test was performed to estimate critical differences among various treatments.

3. RESULTS AND DISCUSSION

3.1 Growth parameters

Observations on different growth parameters revealed that significantly shorter plant height at harvest was observed in weedy check (112.5 cm), whereas taller plant height was noticed in weed free check (145.6 cm) (Fig. 1.). However, weed free check was statistically on par with application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS (138.8 cm) and atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (136.9 cm), which might be due to the effect of chemicals on the weeds that reduced the weed density and dry weight that results to supply sorghum plants with optimum nutrients, moisture, space and sunlight for the potential crop growth by increased internode length through hastened cell multiplication and cell elongation due to improved ability of the crop to withstand strongly during critical period

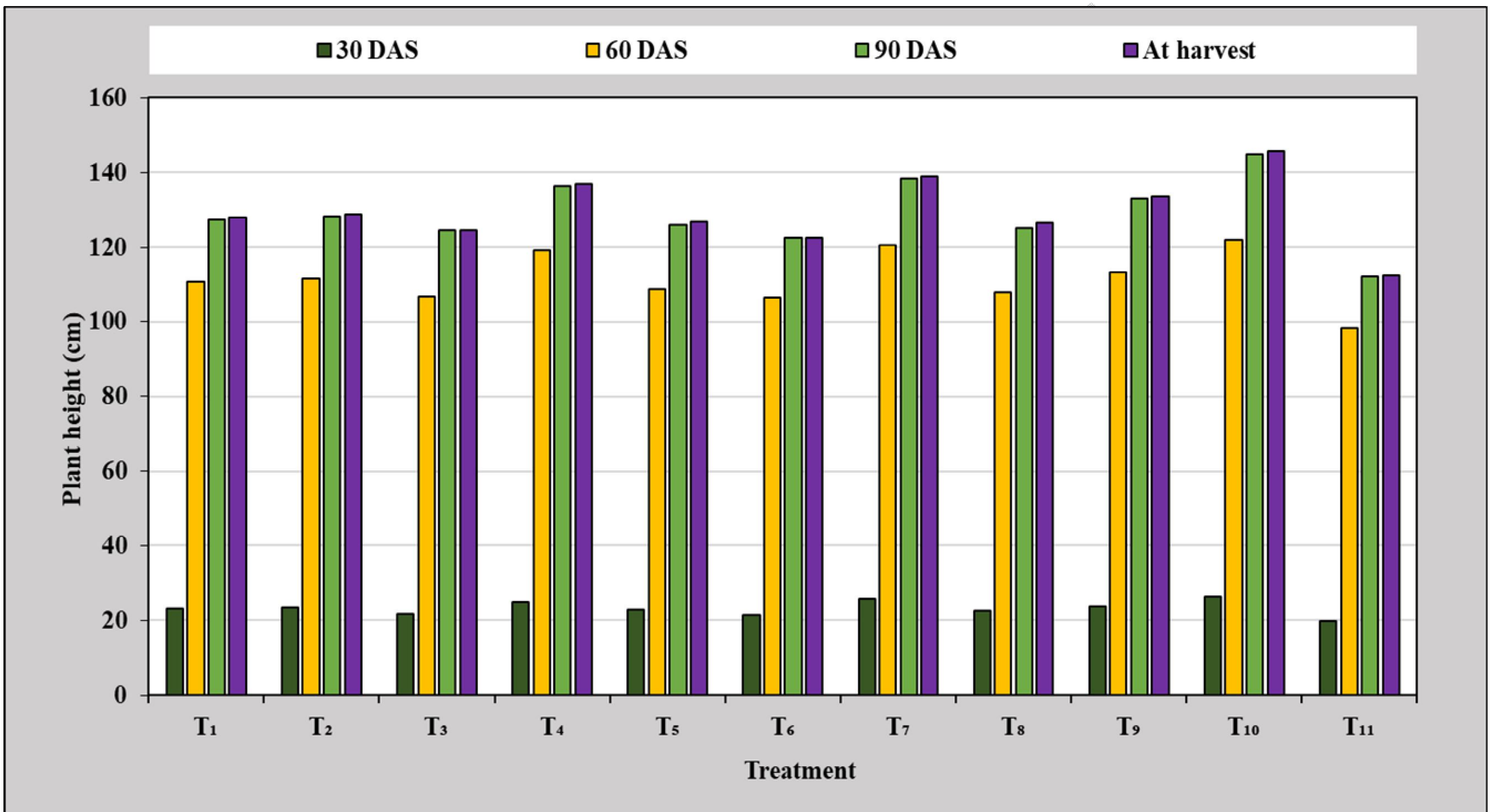

Fig. 1. Plant height of *kharif* grain sorghum as influenced by different weed management practices

of crop-weed competition. These results are in close conformity with the data recorded by Rajesh Patil, 2020[10] in sorghum crop and Acharya *et al*., 2023[11] in wheat crop with the use of metribuzin as PoE. Among herbicide treatments application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PoE at 15-18 DAS, pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS and pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS had shown phytotoxicity on sorghum crop so plant height was shorter than other treatments (126.4, 124.6 and 122.7 cm, respectively). These results are supported by the findings of Goodrich *et al*., 2018[12], Matte *et al*., 2021[13] and Naveenkumar, 2022 [14].

At 30, 60, 90 DAS and at harvest, number of leaves per plant had shown significant differences among the various treatments involved in this study (Table 1). The maximum number of leaves per plant were found in weed free check (7.8, 11.1, 11.7 and 9.2, respectively), whereas the minimum number of leaves per plant were noticed in weedy check (5.2, 7.4, 7.8 and 6.2, respectively). Among different herbicide treatment, application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS (7.2, 10.7, 11.2 and 8.9, respectively). The next best treatment is application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (6.9, 10.1, 10.7 and 8.4, respectively). Minimum number of leaves per plant was noticed in pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (6.3, 8.7, 8.8 and 6.9, respectively)

Significantly higher leaf area and leaf area index (30.2 dm^2 plant^{-1} and 4.47, respectively at harvest) was recorded with weed free check at harvest stage (Table 1). Among the herbicide treatments application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS (29.1 dm^2 plant^{-1} and 4.31, respectively) and atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (27.9 dm^2 plant^{-1} and 4.13, respectively) was found on par with weed free check. Whereas lower leaf area and leaf area index was recorded with weedy check (19.7 dm^2 plant^{-1} and 2.92, respectively) and in herbicide treatment pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (22.0 dm^2 plant^{-1} and 3.26, respectively).

Total dry matter production in *kharif* grain sorghum differed significantly due to different weed management treatments shown in Fig. 2. Higher total dry matter production at harvest was recorded with weed free check, atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS, atrazine 50% WP @ 500 g *a.i.*

Table 1. Effect of different weed management practices on number of leaves, leaf area and leaf area index in *kharif* grain sorghum

Treatment	Number of leaves (plant^{-1})				Leaf area (dm^{2} plant^{-1})				Leaf area index			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T_1	6.6	9.4	9.8	7.7	12.0	25.2	29.3	25.6	1.78	3.73	4.35	3.79
T_2	6.6	9.5	9.9	7.8	12.2	25.8	29.9	26.1	1.81	3.82	4.43	3.87
T_3	6.3	8.9	9.0	7.1	10.6	21.4	25.4	24.1	1.57	3.17	3.76	3.57
T_4	6.9	10.1	10.7	8.4	13.1	28.0	32.1	27.9	1.94	4.15	4.75	4.13
T_5	6.5	9.3	9.4	7.6	11.5	24.3	28.3	24.4	1.70	3.60	4.19	3.61
T_6	6.3	8.7	8.8	6.9	10.3	19.6	23.8	22.0	1.53	2.90	3.52	3.26
T_7	7.2	10.7	11.2	8.9	13.8	28.9	33.3	29.1	2.04	4.28	4.93	4.31
T_8	6.4	9.2	9.2	7.3	11.1	23.6	27.6	24.0	1.64	3.50	4.09	3.56
T_9	6.7	9.9	10.2	8.1	12.7	27.2	31.0	27.1	1.88	4.03	4.60	4.02
T_{10}	7.8	11.1	11.7	9.2	14.4	30.6	34.5	30.2	2.13	4.53	5.11	4.47
T_{11}	5.2	7.4	7.8	6.2	8.8	17.5	21.3	19.7	1.31	2.59	3.16	2.92
S.Em. ±	**0.3**	**0.4**	**0.4**	**0.3**	**0.5**	**1.0**	**1.1**	**1.0**	**0.08**	**0.15**	**0.16**	**0.15**
C.D. (P=0.05)	**1.0**	**1.1**	**1.2**	**0.9**	**1.5**	**3.0**	**3.3**	**2.9**	**0.22**	**0.44**	**0.49**	**0.43**

Note: WG: Water-dispersible granules; **WP:** Wettable powder; **PE:** Pre-emergence; **PoE:** Post-emergence; ***fb*:** Followed by; **HW:** Hand Weeding; **IC:** Inter cultivation; **DAS:** Days after sowing; ***a.i.*:** Active ingredient

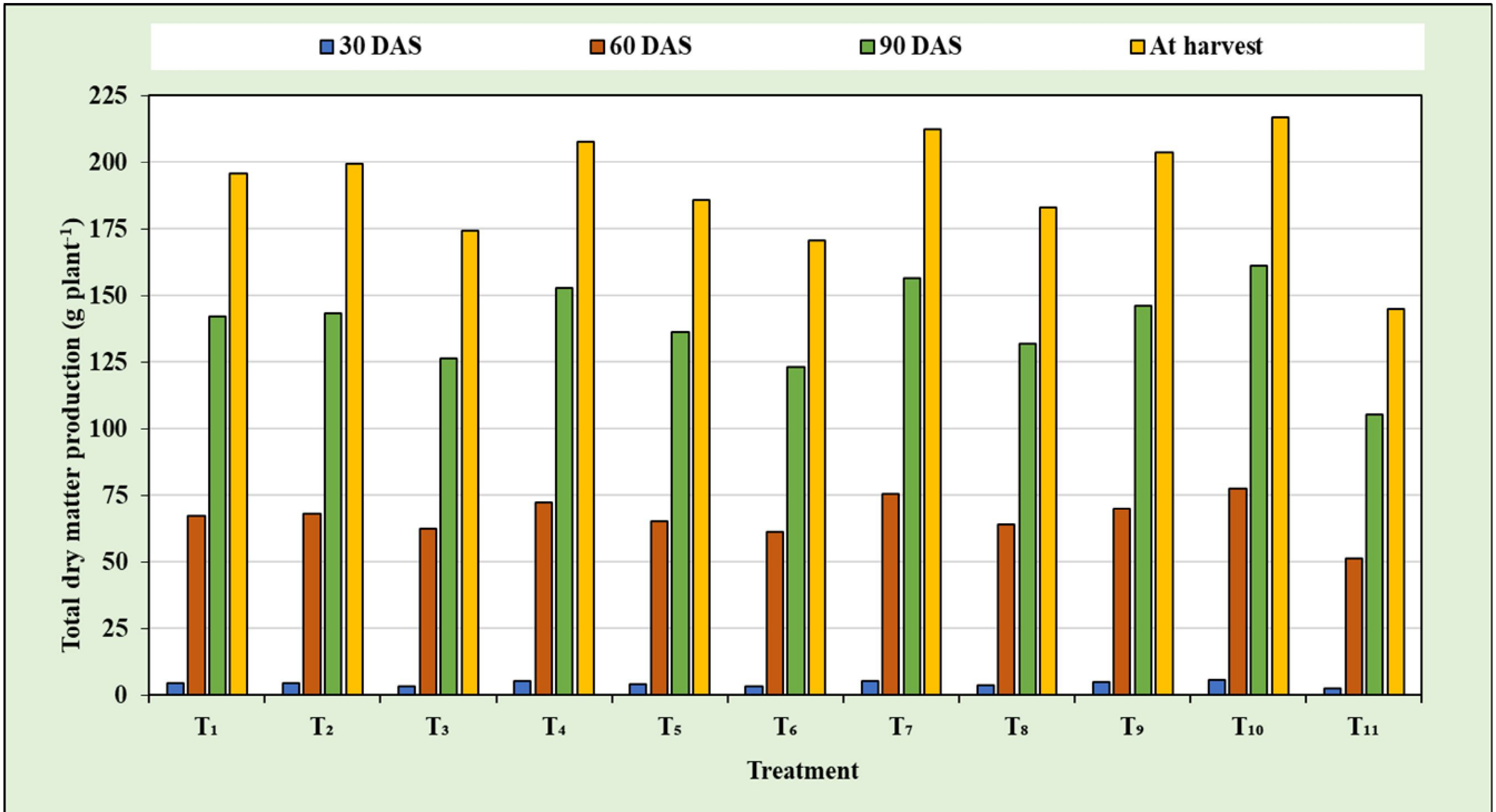

Fig. 2. Total dry matter production in *kharif* grain sorghum plant as influenced by different weed management practices

ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS and farmers' practice. Weedy check recorded lower total dry matter production at harvest. Application of atrazine (PE) followed by metribuzin (PoE) was recorded higher growth parameters than other herbicide treatment similar results were also reported with Rajesh Patil, 2020[10] in sorghum crop and Acharya *et al.*, 2023[11] in wheat crop with the use of metribuzin as PoE. Whereas, lower growth parameters were noticed in pyroxasulfone applied treatments this is because it had shown phytotoxicity on sorghum crop. These results are supported by the findings of Goodrich *et al.*, 2018[12], Matte *et al.*, 2021[13] and Naveenkumar, 2022[14].

3.2 Yield components and yield

The data pertaining to yield attributing characters and yield are presented (Tables 2). The observations on length of ear head (cm), number of grains per earhead, grain weight per earhead (g), test weight (g 1000 grains^{-1}), grain yield (kg ha^{-1}), stover yield (kg ha^{-1}), harvest index (%) and weed index as influenced by various weed management treatments.

It was observed that the length of earhead obtained from weed free check had shown significantly higher length of earhead (35.8 cm) than the other treatments which was statistically on par with application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS (34.8 cm) and atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (34.4 cm). The next best treatment was farmers' practice wherein higher length of earhead of (33.4 cm) had been observed. Whereas significantly shorter length of earhead was recorded in weedy check (22.5 cm). The number of grains per earhead (2377) produced was significantly higher in weed free check than all other treatments (Table 2**)**. Among the chemical weed management practices, application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS had resulted in significantly higher number of grains per earhead (2351) which was statistically comparable with the application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (2317) and farmers' practice (2280). However, the weedy check produced the minimum number of grains per earhead (1828). Among the herbicide treatments, significantly higher grain weight per plant was recorded with the application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS (58.3 g plant^{-1}) However, it was found on par with the application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (57.9 g plant^{-1}). The next best treatment was farmers' practice (56.3 g plant^{-1}). The significant variation in grain weight per plant due to different weed management practices might be due to higher length of earhead and grains per

Table 2. Yield components and yield as influenced by different weed management practices in *kharif* grain sorghum

Treatment	Length of earhead (cm)	Number of grains earhead^{-1}	Grain weight (g plant^{-1})	Test weight (g 1000 grains^{-1})	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
T_1	31.2	2215	52.1	30.2	2589	7898	24.7
T_2	32.1	2238	53.3	30.8	2606	7951	24.7
T_3	28.9	2045	45.2	29.7	2281	7110	24.3
T_4	34.4	2317	57.9	31.0	2809	8395	25.1
T_5	30.4	2156	49.3	30.1	2516	7473	25.2
T_6	28.5	1973	42.5	29.6	2246	6868	24.6
T_7	34.8	2351	58.3	31.1	2905	8576	25.3
T_8	29.3	2118	46.9	29.8	2380	7362	24.4
T_9	33.4	2280	56.3	30.9	2722	8163	25.0
T_{10}	35.8	2377	59.8	31.3	3049	8880	25.5
T_{11}	22.5	1828	34.6	29.5	1536	5673	21.3
S.Em. ±	**0.5**	**28**	**0.7**	**1.8**	**89**	**178**	**0.6**
C.D. (P=0.05)	**1.4**	**82**	**2.0**	**NS**	**262**	**526**	**1.7**

Note: WG: Water-dispersible granules; **WP:** Wettable powder; **PE:** Pre-emergence; **PoE:** Post-emergence; ***fb*:** Followed by; **HW:** Hand Weeding; **IC:** Inter cultivation; **DAS:** Days after sowing; ***a.i.*:** Active ingredient; **NS:** Non-significant earhead. The results pertaining to this investigation w.r.t number of grains per earhead was corroborate with the investigations carried out by Patel *et al*., 2006[15] and Mallikarjun, 2008[16] in maize crop and Ahlawat *et al*., 2023[17] in wheat crop. The significant variation was not observed with respect to test weight due to different weed management practices. As it was one of the genetic characters, there was non-significant difference in test weight.

Significantly higher grain and stover yield (3049 and 8880 kg ha^{-1}, respectively) was observed in weed free check as compared to weedy check (1536 and 5673 kg ha^{-1}, respectively). Among the herbicide treatments, application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS has recorded significantly higher grain and stover yield (2905 and 8576 kg ha^{-1}, respectively), subsequently application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS produced higher grain yield (2809 and 8395 kg ha^{-1}, respectively) (Table 2). The next best treatment is farmers' practice had produced grain yield of 2722 and 8163 kg ha^{-1}. This increase in grain yield can be attributed to the effective control of a wide range of weeds during the critical period of crop-weed competition. Weeds are notorious for competing with crops for light, space, moisture and nutrients, but their management has created a favorable environment for optimal growth and yield attributes. The combined impact of these yield components has led to a significant rise in grain yield of sorghum. Application of atrazine as PE and metribuzin as PoE resulted in control of weeds and higher stover yield can be attributed to enhanced growth parameters such as increased plant height, greater number of green leaves per plant, expanded leaf area and higher leaf area index. The vegetative development of the crop is predominantly influenced by effective weed control. Optimal weed management ensures maximum nitrogen utilization by the crop, directly impacting plant growth. This cumulative enhancement in vegetative growth significantly boosts the accumulation of dry matter, consequently leading to increased stover yield. These results are in conformity with Patel *et al*., 2006[15] in maize crop and Ahlawat *et al*., 2023[17] in wheat crop with the use of metribuzin herbicide. Harvest index significantly differ due to various weed management practices. However, numerically higher harvest index was recorded in weed free check and followed by application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS (25.5 and 25.3%, respectively) and lower harvest index was recorded in weedy check (21.3%) (Table 2).

3.3 Economics

The higher cost of cultivation was observed in weed free check (Rs. 46726 ha^{-1}) due to repeated hand weeding operation to keep it weed free throughout the period of investigation (Table 3). The lower cultivation cost was noticed in weedy check (Rs. 34426 ha^{-1}) because of non-adoption of any of the weed management methods making it as the control treatment. Among different herbicide treatments, application of metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS had recorded lower cultivation cost of Rs. 36303 ha^{-1} followed by metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (Rs. 37081 ha^{-1}).

Among the herbicide treatments, application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS had resulted in higher gross returns (Rs. 119425 ha^{-1}) followed by atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (Rs. 115787 ha^{-1}). The lower gross returns were recorded in pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (Rs. 93039 ha^{-1}). Significantly higher net returns was recorded from atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS (Rs. 80988 ha^{-1}) was statistically on par with atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (Rs. 77374 ha^{-1}), weed free check (Rs. 78256 ha^{-1}) and metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS (Rs. 71605 ha^{-1}), while lower net returns (Rs. 32119 ha^{-1}) was noticed in weedy check. The maximum ratio (3.11) was recorded in atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PoE at 15-18 DAS applied treatment which was statistically on par with atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* 2,4-D Na Salt 80% WP @ 750 g *a.i.* ha^{-1} as PoE at 25 DAS (3.01) and metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS (2.97). Whereas the minimum benefit-cost ratio (1.93) was recorded in weedy check. This might be due to a better weed control and had attained higher grain and stover yield. These results are in accordance with findings of Rajesh Patil, 2020[10]. Application of metribuzin as post-emergent recorded higher B:C similar results were found with Nanher *et al.*, 2015[18] in wheat crop.

Table 3. Economics of *kharif* grain sorghum cultivation as influenced by different weed management practices

Treatment	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	Benefit cost ratio
T_1	38943	107199	68256	2.75
T_2	36303	107908	71605	2.97
T_3	38789	94903	56114	2.45
T_4	38413	115787	77374	3.01
T_5	37081	103561	66480	2.79
T_6	39747	93039	53292	2.34
T_7	38437	119425	80988	3.11
T_8	40186	98853	58667	2.46
T_9	44997	112285	67288	2.50
T_{10}	46726	124982	78256	2.67
T_{11}	34426	66545	32119	1.93
S.Em. ±	**-**	**3237**	**3237**	**0.08**
C.D. (P=0.05)	**-**	**9550**	**9550**	**0.24**

Note: WG: Water-dispersible granules; **WP:** Wettable powder; **PE:** Pre-emergence; **PoE:** Post-emergence; ***fb*:** Followed by; **HW:** Hand Weeding; **IC:** Inter cultivation; **DAS:** Days after sowing; ***a.i.*:** Active ingredient

4. CONCLUSION

Based on the experimental results, it was found that the use of pre-emergence application of atrazine 50% WP @ 500 g *a.i.* ha^{-1} followed by post-emergence application of metribuzin 70% WP @ 100 g *a.i.* ha^{-1} at 15-18 DAS was better to weed control for a longer duration, resulting in higher productivity and profitability. Moreover, the sequential application of herbicides helps in achieving higher net returns and B:C. Application of pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as both pre and post emergent as shown phytotoxicity on sorghum crop.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

REFERENCES

1. Anonymous. USDA, Foreign Agriculture service. India - Area, yield and production for the year 2023-24. https://ipad.fas.usda.gov. 2024.
2. Shahbandeh. Leading sorghum producers worldwide 2019-2020. Statista report. *www.statista.com*; 2020.
3. Anonymous. Indiastat, Karnataka - Area, yield and production for the year 2022-23. https://www.indiastat.com/ 2023.
4. Lagoke STO, Shebayan JAY, Adeosun JO, Iwafor ENO, Olukosi J, Adu A, Olufajo O, Emechebe A, Zaria N, Adeoti A and Onyibe J. Survey of striga control methods in maize, sorghum and cowpea in the Nigerian Savanna. Pan African Striga Control Network. 1990;23-29.
5. Mishra JS. Critical period of weed competition and losses due to weeds in major field crops. Farmers and parliament. 1997;33(6): 19-20.
6. Subbiah BV and Asija GL. A rapid procedure for determination of available nitrogen in soil. Current Sci. 1956;25: 259-260.
7. Olsen SR. *Estimation of available phosphorus in soils by extraction with sodium bicarbonate* (No. 939). US Department of Agriculture; 1954.

8. Jackson ML. *Soil Chemical Analysis*. Prentice Hall of India Private Ltd., New Delhi, 1973;pp 498.
9. Panse VG and Sukhatme PV. *Statistical Methods for Agricultural Workers*, ICAR Publication, New Delhi, 1967;359 p.
10. Rajesh Patil V. Weed management in *kharif* grain sorghum (*Sorghum bicolor* L.). M. Sc. (Agri.) Thesis, Univ. Agric. Sci. Raichur, Karnataka (India); 2020.
11. Acharya P, Bhattarai RK, Subedi R and Shrestha A. Effect of herbicides doses and dates of application on weed and weed indices in wheat. J. Plant Prot. Res. 2023; 8: 115-124.
12. Goodrich LV, Butts□Wilmsmeyer CJ, Bollero GA and Riechers DE. Sequential pyroxasulfone applications with fluxofenim reduce sorghum injury and increase weed control. J. Agron. 2018;110(5): 1915-1924.
13. Matte WD, Oliveira JRS, Constantin J, Mendes RR, Padovese LM and Tseng TM. Bioindicators selection to monitoring pyroxasulfone mobility and persistence in soil. J. Res. Weed Sci. 2021;4(2): 142-150.
14. Naveenkumar R. Exploration of various modes of weed management in forage sorghum [*Sorghum bicolor* (L.) Moench]. M. Sc. (Agri.) Thesis, G. B. Pant Univ. Agric. Tech., Pantnagar, Uttarakhand (India);2022.
15. Patel VJ, Upadhyay PN, Patel JB and Patel BD. Evaluation of herbicide mixtures for weed control in maize (*Zea mays* L.) under middle Gujarat conditions. J. Agric. Sci. 2006;2(1): 81-86.
16. Mallikarjun KS. Effect of sequential application of herbicides in maize (*Zea mays* L.) in northern transition zone of Karnataka. M. Sc. (Agri.) Thesis, Univ. Agric. Sci., Dharwad (India);2008.
17. Ahlawat I, Kamboj BR, Yadav DB and Dahiya G. 2023. Effect of different doses and method of application of metribuzin on wheat crop under rice residue cover situations. J. Pharm. Innov. 2023;12(5): 4101-4105.
18. Nanher AH, Singh R, Yadav S, Tyagi S, Kumar V, Singh AK and Shamim SA. Effect of metribuzin in combination with post-emergence herbicide on weed and productivity of wheat. The Bioscan. 2015;10(3): 1345-1348.