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Examination of the effects of various weed control treatments on weed management indices in *Kharif* grain sorghum [*Sorghum bicolor* (L.) Moench]

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Abstract
An experiment was conducted to evaluate the efficacy of several herbicides used separately and in combination against weeds in grain sorghum at the Sorghum Research Station, VNMKV, Patbhani, (MS), India. There were 16 treatments in total: T_1: Atrazine 50 WP @ 0.50 kg a.i./ha , T_2: Metolachlor 50% EC @ 1.00 kg a.i./ha as PE , T_3: Pyroxasulfone 85% w/w WG @ 0.1275 kg , T_4: T_1 + Bentazone 480 g/l SL @ 960 g a.i./ha , T_5: T_1 + Mesotrione 2.27% w/w + Atrazine , T_6: T_1 + Carfentrazone ethyl 40% DF @ 20 g, T_7: T_2 + Bentazone 480 g/l SL @ 960 g a.i./ha , T_8: T_2 + Mesotrione 2.27% w/w + Atrazine , T_9: T_2 + Carfentrazone ethyl 40% DF @ 20 g , T_{10}: T_3 + Bentazone 480 g/l SL @ 960 g a.i./ha , T_{11}: T_3 + Mesotrione 2.27% w/w + Atrazine , T_{12}: T_3 + Carfentrazone ethyl 40% DF @ 20 g , T_{13}: T_1 (PE & POE), T_{14}: T_1 + 2,4-D Na Salt 80 WP@ 0.75 kg a.i./ha and T_{15}: Weed free (15 and 35 DAS) replicated twice in randomized block design during growing seasons of 2021-22. All chemical weed control treatments significantly reduced the weed infestation over weedy check, according to weed indices that were determined. Study demonstrates that pre-emergence application T_2: Lower grain sorghum yield compared to atrazine treatments and T_3: Pyroxasulfone 85% w/w WG @ 0.1275 kg a.i./ha as PE; both treatments contained 50% EC at 1.00 kg a.i./ha as PE. T_3: The minimum germination recoded as 62% WCE was reported for sorghum grain when pyrosulfone was applied at a rate of 85% w/w WG at 0.1275 kg a.i./ha. Management T_{15}: Compared to the treatment, weed-free areas with 15 and 35 DAS produced the maximum yield (2605 kg/ha). T_{14}: T_1 coupled with 2,4-D Na Salt 80 WP@ 0.75 kg a.i./ha T_1: 100 WP at 0.50 kg a.i./ha (PE) + T_6: T_1 + 40% Carfentrazone ethyl 40% DF @ 20 g a.i./ha as PoE at 3-4 leaves. This may be because of a larger accumulation of growth and yield qualities of grain sorghum due to lesser weed-crop competition, since these treatments show higher WCE and lower WI compared to the remainder of the treatment and are statistically shown to be at par grain yield of grain sorghum as in weed free condition.

Keywords: Sorghum weed management, herbicides, weeds indices

Introduction

The main uses of grain sorghum cultivation are as feed, animal feed, fence material, poultry feed, and even as a source of ethanol. Among grain sorghum's primary benefits is its capacity to maintain yields under conditions of vegetative drought stress (Kebede *et al*. 2001) [4]. Because grains sorghum have sophisticated plant responses, they can adjust to pre-reproduction drought conditions, even when severe drought during reproduction can reduce yields dramatically (Crasta *et. al*. 1999) [8]. In many dry and semi-arid parts of the world, sorghum is a staple crop because of its unique qualities (Dicko *et al*. 2006) [2]. In Maharashtra, production processes do not completely utilize the crop known as kharif Grain Sorghum Production. Low grain sorghum commodity prices decrease a grower's potential for a significant net return in the event that poor yields are attained. These meager returns frequently discourage producers from planting a risky crop such as grain sorghum and cause them to rely on higher-priced cash crops. season may be challenging due to the occasionally unequal distribution of rainfall, which leaves weeds in their crucial growth stages and ultimately reduces productivity farmers of corn, soybeans, rice, and cotton (*Gossypium hirsutum* L.) may be able to handle this problem by using new herbicide-resistant crop technology, but farmers of grain sorghum are limited to a small number of labeled herbicides. Growers of grain sorghum have been compelled to diversify their weed management practices due to this limited choice of herbicides. Grain sorghum weed control during the wet season is particularly difficult because to the scarcity of accessible herbicides to growers and irregular rainfall cause limit to mechanical weeding. Additionally, the only herbicide used on sorghum is atrazine. However, there are currently concerns regarding atrazine, which has prompted researchers to look for alternatives. Additionally, a combination of PE and PoE herbicides may be able to assist control weeds in grain sorghum. Grain sorghum yields were lowered more by broadleaf weed competition than by competition from grass species or mixes of both types of weeds. However, grain sorghum yields have not decreased due to weed competition in the sorghum crop that was present in the first two weeks following crop emergence. The removal of weeds at 1, 2, or 3 weeks after planting and every week after that did not affect sorghum yields; however, if weeds were left unremoved for 4, 5, 6, or 8 weeks, yields significantly decreased. Little production loss from weeds appearing later was observed in sorghum that was kept free of weeds during the first four weeks following planting. Sorghum yields from weeds remaining after two cultivations were 38% lower than those from plots that received weekly weeding (O. C. Burnside and G. A. Wicks, 2017) [7].

Materials and Methods

AICSIP, Sorghum Research Station, VNMKV, Parbhani location, which is located at latitude 19.251624 and longitude 76.767015. The black cotton soil type under investigation was clayey, having a pH of 7.6 and 0.53 organic matter with sixteen treatments and two replications, the experiment was carried out in a randomized complete-block design. Gross: 4.50 m x 5.10 m and net: 2.70 m x 4.50 m are the dimensions of the plot. Parbhani Shakti sorghum genotype was utilized in this experiment, with spacing of 45 cm x 15 cm from row to row and plant to plant was maintain. Fertilizer and plant protection were applied in accordance with recommendations. The experiment was sown on July 17, 2021, and harvested on November 23, 2021.

Treatments: 16

T_1: Atrazine 50 WP @ 0.50 kg a.i./ha
T_2: Metolachlor 50% EC @ 1.00 kg a.i./ha as PE
T_3: Pyroxasulfone 85% w/w WG @ 0.1275 kg
T_4: T_1 + Bentazone 480 g/l SL @ 960 g a.i./ha
T_5: T_1 + Mesotrione 2.27% w/w + Atrazine
T_6: T_1 + Carfentrazone ethyl 40% DF @ 20 g
T_7: T_2 + Bentazone 480 g/l SL @ 960 g a.i./ha
T_8: T_2 + Mesotrione 2.27% w/w + Atrazine
T_9: T_2 + Carfentrazone ethyl 40% DF @ 20 g
T_{10}: T_3 + Bentazone 480 g/l SL @ 960 g a.i./ha
T_{11}: T_3 + Mesotrione 2.27% w/w + Atrazine
T_{12}: T_3 + Carfentrazone ethyl 40% DF @ 20 g
T_{13}: T_1 (PE & POE)
T_{14}: T_1 + 2,4-D Na Salt 80 WP@ 0.75 kg a.i./ha
T_{15}: Weed free (15 and 35 DAS)
T_{16}: Weedy check

Indices used for study

Weed density: Twenty days following the application of pre-emergence herbicides, which corresponds with the three-leaf stage of crop development, weed counts and species dispersion were conducted. Twenty days following the use of post-emergence herbicide, a second weed count was conducted, and a third during harvest. Weed species were counted and identified using 1 m^2 quadrats that were thrown at random into each plot.

Weed dry matter: The measurements were made by harvesting all the above-ground growth of weeds within the 1 m^2 quadrat that was randomly tossed into each experimental plot, taking the measurements at 20 DAS of PE and 20 DAS of PoE. After gathering the weeds and placing them in a paper bag, they were oven-dried to a consistent weight at 60°C. Next, the oven-dried weight in grams for each plot was translated to $kgha^{-1}$.

Weed control efficiency (WCE) is the percentage of weed reduction due to a weed control treatment and is a measure of effectiveness of control method (Das, 2008).

$$WCE = \frac{DMC\text{-}DMT}{DMC} \times 100$$

Weed persistence index (c) = (Mishra *et al*. 2016) [6]

$$\frac{\text{Dry weight of weeds in treated plot}}{\text{dry weight of weeds in control plot}} \times \frac{\text{weed count in the control plot}}{\text{weed count in the treated plot}}$$

Weed Control Index (WCI): worked out taking into consideration the reduction in weed population in treated plot over weed population in unweeded check. It is expressed in %.

$$WCI = \frac{WPC\text{-}WPT}{WPC} \times 100$$

Where,
WPC = Weed population in control (unweeded) plot.
WPT = Weed population in treated plot.

Herbicide Efficiency Index (HEI) = Indicates the weed killing potential of a herbicide treatment and its phytotoxicity on the crop

$$HEI = \frac{(YT\text{-}YC)/YC)}{WT/WC}$$

Agronomic Management Index (AMI)

$$AMI = \frac{Yt-yc}{yc} - \frac{wc-wt}{wc} / \frac{wc-wt}{wc}$$

Where, YT = Yield of treated plot.
YC= Yield of control (unweeded) plot.
WC = Weed dry weight in control (unweeded) plot.
WT= Weed dry weight in treated plot.

Results and Discussion

Echinochloa colona, Cynodon dactylon, Digitaria sanguinalis, and Dactyloctenium aegyptium were the most common grassy weed species identified in the experimental site. Digera arvensis and Trianthema portulacastrum were the most common broad-leaf weeds, and Cyperus rotundus was the most common sedge species. According to Table 1, treatments T_1, T_4, T_5, T_{13}, T_{14}, and T_{16} with post-emergence (PoE) application had the significantly lowest weed density and dry weight at 20 days after the PE herbicide was sprayed, compared to the weedy check. Similarly, the same treatment T_1, T_4, T_5, T_{13}, T_{14}, and T_{16} showed significantly lower dry weight and weed density after 20 days following PoE administration compared to the weedy control. Treatment T_1 outperformed the other herbicide treatments, with the exception of T_{15}, where it was on par, in terms of grain yield (2450 kg ha-1) due to its low weed flora invasion. Among the various weed control treatments, treatment T_{16} (weedy check) was found to have the worst weed management indices because of the highest level of weed infestation. Weed management indices improved when atrazine was applied as PE and PoE, regardless of the herbicide dose used alone or in combination (Table 1).

Table 1: Weed density and weed dry weight as affected by different weed control treatments in *kharif* sorghum

Treatments detail	Total Weed density (No. m^{-2})		Total Weed dry weight (g m^{-2})		Grain yield (Kg/ ha)
	At 20 days after PE	At 20 days after PoE	At 20 days after PE	At 20 days after PoE	
T_1: Atrazine 50 WP @ 0.50 kg a.i./ha	8(16)	6(14)	5	4	2450
T_2: Metolachlor 50% EC @ 1.00 kg a.i./ha as PE	23(28)	13(21)	12	9	1925
T_3: Pyroxasulfone 85% w/w WG @ 0.1275 kg	19(26)	11(20)	12	8	0
T_4: T_1 + Bentazone 480 g/l SL @ 960 g a.i./ha	8(16)	8(16)	4	6	2225
T_5: T_1 + Mesotrione 2.27% w/w + Atrazine	7(15)	6(14)	4	4	2172
T_6: T_1 + Carfentrazone ethyl 40% DF @ 20 g	9(17)	7(15)	4	5	2388
T_7: T_2 + Bentazone 480 g/l SL @ 960 g a.i./ha	19(26)	17(24)	10	12	1900
T_8: T_2 + Mesotrione 2.27% w/w + Atrazine	20(27)	13(21)	11	9	1952
T_9: T_2 + Carfentrazone ethyl 40% DF @ 20 g	19(26)	15(23)	10	10	1795
T_{10}: T_3 + Bentazone 480 g/l SL @ 960 g a.i./ha	20(26)	17(24)	10	11	0
T_{11}: T_3 + Mesotrione 2.27% w/w + Atrazine	18(25)	14(22)	8	9	0
T_{12}: T_3 + Carfentrazone ethyl 40% DF @ 20 g	18(25)	8(16)	10	5	0
T_{13}: T_1 (PE & POE)	7(15)	6(13)	5	4	2339
T_{14}: T_1 + 2,4-D Na Salt 80 WP@ 0.75 kg a.i./ha	8(16)	8(16)	4	5	2389
T_{15}: Weed free (15 and 35 DAS)	4(11)	4(11)	2	3	2605
T_{16}: Weedy check	57(19)	58(49)	33	39	1422
SE(m)$\pm$	1.87	1	1	0.85	118
CD at 5%	5.70	4	4	2.59	360

Results T_1, T_4, T_5, T_{13}, and T_{14} exhibited considerably greater WCI, WCE, and HEI and significantly lower WPI twenty days after the application of PE herbicide treatment, as shown in Tables 2 and 3. These results were statistically comparable to treatments T_{15}. Better weed management indices were found in treatments T_1, T_4, T_5, T_{13}, and T_{14} due to the lowest weed infestation. WMI and AMI at 20 DAS were not significantly affected by any of the weed management interventions. T_{10}: T_3 + Bentazone 480 g/l SL @ 960 g a.i./ha, T_{11}: T_3 + Mesotrione 2.27% w/w + Atrazine, and T_{12}: T_3 + Carfentrazone ethyl 40% DF @ 20 g all had a negative impact. Treatment T_3: Pyroxasulfone 85% w/w WG @ 0.1275 kg both alone and in combination with PoE herbicide.

However, table 2 and 3 show that application of Atrazine alone and as post-emergence (T_1 and T_{13}) successful to control weed in grain sorghum than other combination of herbicide. At 20 days after application of PoE herbicide, efficacy of different PRE herbicides drops differently. which was discovered to be on level with Treatment T_{15} (weed free). More frequently, atrazine is applied to prevalent weeds in sorghum production systems as a broad-spectrum pre- and post-emergence herbicide. Atrazine has been found to be useful in controlling some weeds, depending on usage rate and application time (pre-emergence versus post-emergence) such as barnyard grass [*Echinochloa crus-galli* (L.) *P. Beauv*], *giant foxtail* (*Setaria faberi Herrm*.), *yellow foxtail* [*Setaria pumila* (*Poir*.) *Roem*. *& Schult*.], *red rice* (*Oryza sativa* L.), *quackgrass* [*Elymus repens* (L.) *Gould*], *morning glory* (*Ipomoea ssp*.), *eastern black night shade* (*Solanum ptychanthum Dunal*), *common cocklebur* (*Xanthium strumarium* L.), *common ragweed* (*Ambrosia artemisiifolia* L.), *giant ragweed* (*Ambrosia trifida* L.), *jimsonweed* (*Datura stramonium* L.), *kochia* (*Brassica scoparia* (L.) *Scott*), *common lambsquarters* (*Chenopodium album* L.), *Palmer amaranth* (*Amaranthus palmeri S. Wats*.), *redroot pigweed* (*Amaranthus retroflexus* L.), *smartweeds* (*Polygonaceae ssp*.), *velvetleaf* (*Abutilon theophrasti Medik*.), *tall waterhemp* (*Amaranthus tuberculatus* (*Moq*.) *Sauer*), *prickly sida* (*Sida spinosa* L.), *common 3 purslane* (*Portulaca oleracea* L.), and *sicklepod* (*Senna obtusifolia* L.) (Loux *et al*. 2016; Scott *et al*. 2018) [5, 9].

Post-emergence (POE) herbicide treatments (T_4, T_5, T_6, T_{13}, and T_{14}) were compared statistically, and T_{13} produced the highest WCI (48%) and WCE (91%), among other treatments. According to Tables 2 and 3, none of the POE herbicides have a substantial impact on WPI WMI. The relationship between WCE and yield growth and WMI and AMI is inverse. The treatment's effect is represented by the lowest value of WMI and AMI, which indicates higher WCE and relatively higher addition of yield; conversely, larger WMI or AMI indicates lower WCE and relatively lower addition of yield happens. T_{13}: T_1 (PE & POE) at 60 DAS exhibited superior weed management indices in T_1 (Atrazine 50 WP @ 0.50 kg a.i. /ha) and T_{13}: T_1 (PE & POE) at 60 DAS revealed longer suppression of weed growth by this combination (Table 2 and 3).

Table 2: Efficiency Weed Control Index (WCI), Weed control efficiency (WCE) and Weed Persistence Index (WPI) in *kharif* sorghum

Treatments detail	WCI		WCE		WPI	
	At 20 days after PE	At 20 days after PoE	At 20 days after PE	At 20 days after PoE	At 20 days after PE	At 20 days after PoE
T_1: Atrazine 50 WP @ 0.50 kg a.i./ha	43	47	86	90	1.0	1.3
T_2: Metolachlor 50% EC @ 1.00 kg a.i./ha as PE	17	35	65	78	0.9	1.6
T_3: Pyroxasulfone 85% w/w WG @ 0.1275 kg	23	38	65	81	1.1	1.8
T_4: T_1 + Bentazone 480 g/l SL @ 960 g a.i./ha	43	43	89	86	0.9	0.9
T_5: T_1 + Mesotrione 2.27% w/w + Atrazine	44	47	89	90	0.9	1.1
T_6: T_1 + Carfentrazone ethyl 40% DF @ 20 g	41	45	87	88	0.8	1.1
T_7: T_2 + Bentazone 480 g/l SL @ 960 g a.i./ha	23	28	69	70	0.9	1.1
T_8: T_2 + Mesotrione 2.27% w/w + Atrazine	21	35	68	77	0.9	1.4
T_9: T_2 + Carfentrazone ethyl 40% DF @ 20 g	23	31	68	74	0.9	1.2
T_{10}: T_3 + Bentazone 480 g/l SL @ 960 g a.i./ha	21	29	70	72	0.8	1.0
T_{11}: T_3 + Mesotrione 2.27% w/w + Atrazine	25	34	76	77	0.8	1.0
T_{12}: T_3 + Carfentrazone ethyl 40% DF @ 20 g	25	44	69	87	1.0	2.4
T_{13}: T_1 (PE & POE)	44	48	85	91	1.2	1.7
T_{14}: T_1 + 2,4-D Na Salt 80 WP@ 0.75 kg a.i./ha	42	44	89	87	0.8	0.8
T_{15}: Weed free (15 and 35 DAS)	50	50	95	93	0.9	0.8
T_{16}: Weedy check	0	0	0	0	1.0	1.0
SE(m)±	3.28	1.98	4.7	2	0.07	0.23
CD at 5%	9.98	6.05	10.87	6	NS	NS

Table 3: Efficiency Herbicide efficacy index (HEI), Agronomic Management index (AMI) and weed management index (WMI) in *kharif* sorghum

Treatments detail	HEI		WMI		AMI	
	at 20 days after PE	at 20 days after PoE	at 20 days after PE	at 20 days after PoE	at 20 days after PE	at 20 days after PoE
T_1: Atrazine 50 WP @ 0.50 kg a.i./ha	3.3	4.2	0.001	0.001	0.78	0.78
T_2: Metolachlor 50% EC @ 1.00 kg a.i./ha as PE	0.7	1.0	0.001	0	0.38	0.38
T_3: Pyroxasulfone 85% w/w WG @ 0.1275 kg	-2.9	-5.1	-0.002	-0.001	-1.00	-1.00
T_4: T_1 + Bentazone 480 g/l SL @ 960 g a.i./ha	2.0	1.7	0.001	0.001	0.63	0.63
T_5: T_1 + Mesotrione 2.27% w/w + Atrazine	2.4	2.7	0.001	0	0.58	0.58
T_6: T_1 + Carfentrazone ethyl 40% DF @ 20 g	3.3	3.6	0.001	0.001	0.73	0.73
T_7: T_2 + Bentazone 480 g/l SL @ 960 g a.i./ha	0.3	0.4	0.001	0	0.38	0.38
T_8: T_2 + Mesotrione 2.27% w/w + Atrazine	0.1	0.2	0.001	0	0.43	0.44
T_9: T_2 + Carfentrazone ethyl 40% DF @ 20 g	0.1	0.1	0	0	0.31	0.31
T_{10}: T_3+ Bentazone 480 g/l SL @ 960 g a.i./ha	-3.6	-3.6	-0.001	-0.001	-1.00	-1.00
T_{11}: T_3 + Mesotrione 2.27% w/w + Atrazine	-4.2	-4.3	-0.001	-0.001	-1.00	-1.00
T_{12}: T_3 + Carfentrazone ethyl 40% DF @ 20 g	-3.5	-7.7	-0.001	-0.001	-1.00	-1.00
T_{13}: T_1 (PE & POE)	3.2	5.5	0.001	0.001	0.67	0.67
T_{14}: T_1 + 2,4-D Na Salt 80 WP@ 0.75 kg a.i./ha	3.5	2.8	0.001	0.001	0.74	0.74
T_{15}: Weed free (15 and 35 DAS)	10.3	8.5	0.001	0.001	0.89	0.89
T_{16}: Weedy check	0.0	0.0	0	0	0.00	0.00
SE(m)±	0.45	0.73	0	0.001	0.16	0.16
CD at 5%	1.39	2.24	NS	NS	0.49	0.49

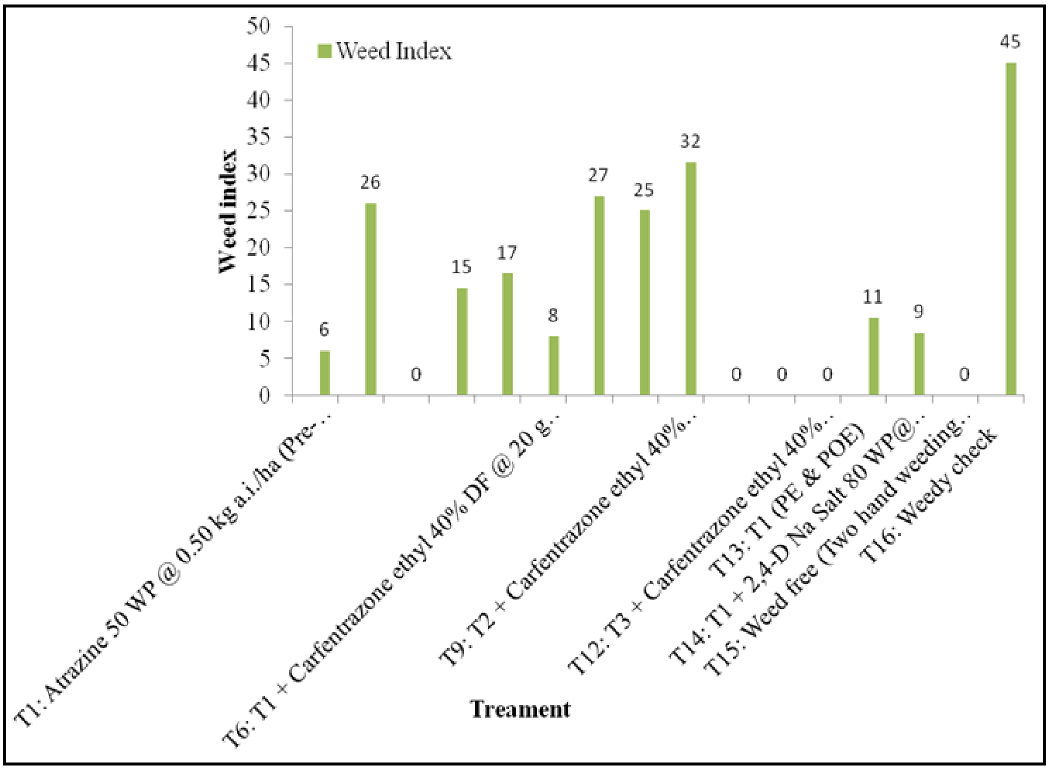

Fig. 1: Effect of different weed control treatments on weed index (%) in *kharif* sorghum

Figure 1 illustrates how the weed index of various weed management techniques in grain sorghum showed that allowing weeds to grow unchecked can result in up to 45% production losses in pigeon pea. In terms of weed index, T_{15} (weed free) was the best treatment; T_1, T_6, T_{13}, and T_{14} were closely behind. Herbicides that effectively suppressed weed development in their early stages through pre-emergence and late stages through post-emergence were mostly responsible for the reduced weed growth in these treatments. The unweeded check showed the highest rate of weed growth. Sequential treatment was shown to be generally better than applying herbicides all at once. Sharma *et al*. confirmed similar findings with sorghum that was normally sown (2000) [10].

Conclusion

Weed infestation can cause a 45% reduction in the grain output of *kharif* sorghum. The management of weed in grain sorghum can be achieved through the pre-emergence treatment of atrazine alone or in conjunction with it to enhance weed indices in the grain sorghum. Nonetheless, the results indicate that treatment T_1, T_6, T_{13}, T_{14}, and T_{15} of the various herbicide treatments had superior outcomes in terms of weed management indices and grain sorghum yield. Thus, for Kharif grain sorghum, pre-emergence treatment of Atrazine 50 WP @ 0.50 kg a.i./ha (T_1), T_{13}: T_1 (PE & POE), and T_{14}: T_1 + 2,4-D Na Salt 80 WP @ 0.75 kg a.i./ha proven to be an efficient and lucrative substitute for the T_{15}: Weed free (15 and 35 DAS).

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