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Weed Dynamics and Productivity of Fodder Sorghum as Influenced by Intercropping and Herbicidal Weed Management Strategies under Semi-Arid Agro-ecology

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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

Sorghum, known for its resilience and adaptability to various climates as a cereal crop, has also become important as a fodder crop due to its broad adaptability. However, it remains highly vulnerable to numerous weed species. In order to manage weeds, field experiment was designed during the Kharif season of 2021-22 at Instructional Farm, Rajasthan College of Agriculture, Udaipur to evaluate weed management in kharif fodder sorghum. The experiment was laid out in a randomized block design with twelve treatments replicated thrice. The treatment combinations are Atrazine 50% WP @ 0.50 kg a.i ha^{-1} as PE (T_1), Metolachlor 50% EC @ 1.00 kg a.i ha^{-1} as PE (T_2), Pyroxasulfone 85% w/w WG @ 0.1275 kg a.i ha $^{-1}$ as PE (T_3), 2,4-D Na salt 80% WP @ 0.75 kg a.i. ha^{-1} as PoE at 20 DAS (T_4), T_1 + Atrazine 50% WP @ 0.50 kg a.i. ha^{-1} as PoE (T_5), T_1 + 2,4-D Na salt 80% WP @ 0.75 kg a.i. ha $^{-1}$ as PoE at 20 DAS (T_6), intercropping with cowpea (1:1 additive series) without herbicides (T_7), intercropping with cowpea (1:1 additive series) + Pendimethalin 30% EC @ 0.75 kg a.i. ha^{-1} as PE (T_8), intercropping with blackgram (1:1 additive series) without herbicides (T_9), intercropping with blackgram (1:1 additive series) + Pendimethalin 30% EC @ 0.75 kg a.i. ha^{-1} as PE (T_{10}), weed free (two hand weeding at 15 and 35 DAS) (T_{11}) and weedy check (T_{12}). The efficacy of the weed management using different treatments was evaluated among different weed flora, weed dry matter T_5 showed the most effective weed control, significantly reducing grass, sedge, and broad-leaved weed populations and dry matter by up to 74.87%. It maintained low weed indices (0.28%), nearly matching manual weeding, and improved fodder sorghum yield. Atrazine-based T_5 proves effective for managing diverse weeds in semi-arid conditions.

Keywords: Additive series; resilience; integrated weed management; weed flora; weed index.

1. INTRODUCTION

India, which houses approximately 20% of the world's livestock population and 17.5% of the global human population, faces significant challenges in meeting the growing demands for both food and fodder. Despite occupying only 2.3% of the world's land area, India must support its ever-increasing population, with human numbers growing at 1.6% annually and livestock numbers at 0.66%. The pressure on limited land resources for food and fodder production is immense. Currently, only 4% of the country's cultivable land is used for fodder crops, creating a severe shortage of green fodder (35.6%), dry crop residues (10.5%), and concentrate feed ingredients (44%). Given this imbalance, it becomes crucial to optimize the available land for fodder cultivation to meet the rising needs of both humans and animals.

In this context, sorghum (*Sorghum bicolor L*. Moench) emerges as a highly valuable crop for fodder production. Forage sorghum, when harvested at the 50% flowering stage, contains 9 to 10% crude protein, 65% neutral detergent fiber, 7 to 42% acid detergent fiber, 32% cellulose, and 21 to 23% hemicellulose on a dry matter basis, which makes it highly valuable. (Kumar et al., 2012). Sorghum is extensively cultivated worldwide, with more than 90% of its production occurring in developing regions, particularly in Africa and Asia. For the 2023–2024 agricultural years, global sorghum production was estimated at around 62.09 million metric tonnes, with India ranking as the fourth-largest producer, contributing approximately 5.27 million metric tonnes, or 8% of the global supply (USDA, 2024). Sorghum's resilience and adaptability to arid and semi-arid conditions make it particularly well-suited for regions like Rajasthan, which often experience water scarcity. Its drought tolerance, high biomass yield, and rapid growth rate make it an ideal choice for fodder in areas where other crops may struggle to thrive.

Sorghum is widely used for silage, hay, and direct grazing due to its excellent palatability and nutritional value, which is comparable to maize (Nicholas et al., 1998). Moreover, when included in the diets of lactating dairy cattle, sorghum has shown promising effects on strategic feed management, improving milk production and overall herd performance (Aydin et al., 1999). Given the significant livestock population in Rajasthan, including cattle, goats, and sheep, a steady supply of quality fodder is essential. However, the full potential of sorghum as a fodder crop is often hindered by weed competition, which reduces crop productivity. Globally, weeds are one of the main challenges hindering food production across agricultural systems (Monteiro & Santos, 2022). Weeds possess several traits that provide them with advantages over sorghum forage. It has been reported that the yield loss in sorghum caused by weeds can range from 15% to 97%, depending on the type and severity of the weed infestation (Thakur et al., 2016). Weeds compete with sorghum for water, nutrients, and light, which negatively affects the growth and yield of the crop. This issue is particularly pressing in semi-arid regions like Rajasthan, where the growing season is short, and water resources are limited. Effective weed management is, therefore, crucial to ensuring high sorghum yields and optimizing its potential as a fodder crop. By minimizing weed pressure, competition is reduced, allowing sorghum to grow efficiently and meet fodder demands.

To address this issue, this study investigates the effectiveness of various weed management strategies in kharif fodder sorghum cultivation. Intercropping enhances beneficial interactions between crops, improving yield stability, optimizing resource use, and naturally suppressing weed growth (Kadziuliene et al., 2009). Studies have shown that intercropping reduces weed density and biomass effectively (Amanullah et al., 2006; Banik et al., 2006; Carruthers et al., 1998; Poggio, 2005). Due to its ecological advantages, intercropping is increasingly integrated into weed management programs alongside chemical treatments, offering a sustainable approach to weed suppression while minimizing herbicide dependence and promoting agro ecosystem health. The research evaluates different treatments and their influence on weed dynamics, sorghum growth, and overall yield. A range of methods, including pre-emergence (PE) and post-emergence (PoE) herbicides, integrated weed management practices such as intercropping with legumes like cowpea and black gram, and traditional weed control methods like manual weeding, are examined.

These treatments are assessed for their impact on weed populations, sorghum dry matter production, and the overall weed index. The aim of the study is to identify sustainable and cost-effective weed management strategies that can enhance fodder sorghum yields, reduce competition from weeds, and improve overall crop efficiency. The findings of this research are expected to provide valuable insights into optimizing weed management practices for fodder sorghum cultivation, which could help to improve productivity, reduce competition from weeds, and support the growing livestock sector in India. Ultimately, this research aims to increase fodder availability, contributing to food security and livestock sustainability in India.

2. MATERIALS AND METHODS

2.1 Experimental Site and Climate

The field investigation carried out during the Kharif season of 2021-22 at Instructional Farm, Rajasthan College of Agriculture, Udaipur, Rajasthan, India. The experimental site lies at an elevation of 581.13 meters above mean sea level, positioned at 24°35′ N latitude and 74°42′ E longitude. This area is classified under Agro-Climatic Zone IVa (semi-arid climate), characterized as the Sub-Humid Southern Plain and Aravalli Hill region of Rajasthan. The weather data for the 2021-22 kharif season was sourced from the agro-meteorological observatory within campus of Rajasthan College of agriculture MPUAT, Udaipur. The experimental site at Rajasthan College of Agriculture, Udaipur, experiences an average annual rainfall of approximately 600.8 mm, predominantly influenced by the south-west monsoon. During the crop growing season, a total of 432.7 mm of rainfall was recorded. Throughout the experimental period, maximum temperatures ranged from 30°C to 34.3°C, while minimum temperatures varied between 10.3°C and 22.3°C. Relative humidity levels fluctuated between 59.9% to 90.4% (maximum) and 25.2% to 79.1% (minimum). Daily sunshine duration ranged from 1.6 to 8.8 hours, and mean evaporation rates were observed between 3.7 and 6.3 mm. Details of the mean weekly meteorological parameters are shown in Fig. 1. Soil health forms the backbone of successful crop production, playing a pivotal role in supporting plant growth, enhancing development, and ultimately shaping yield outcomes. The soil at the experimental site is characterized as clay loam in texture, offering a moderately alkaline reaction with a pH of 7.7 and electrical conductivity of 0.85 dS m^{-1}, indicating non-saline conditions. It contains 0.32% organic carbon, reflecting moderate fertility. The available nutrient status includes 274.14 kg ha^{-1} of nitrogen, 22 kg ha^{-1} of phosphorus (P_2O_5), and 316 kg ha^{-1} of potassium (K_2O), suggesting a reasonably nutrient-rich profile conducive for sorghum cultivation.

2.2 Experimental Design and Details

The experiment was carried out in a randomized block design with three replications.

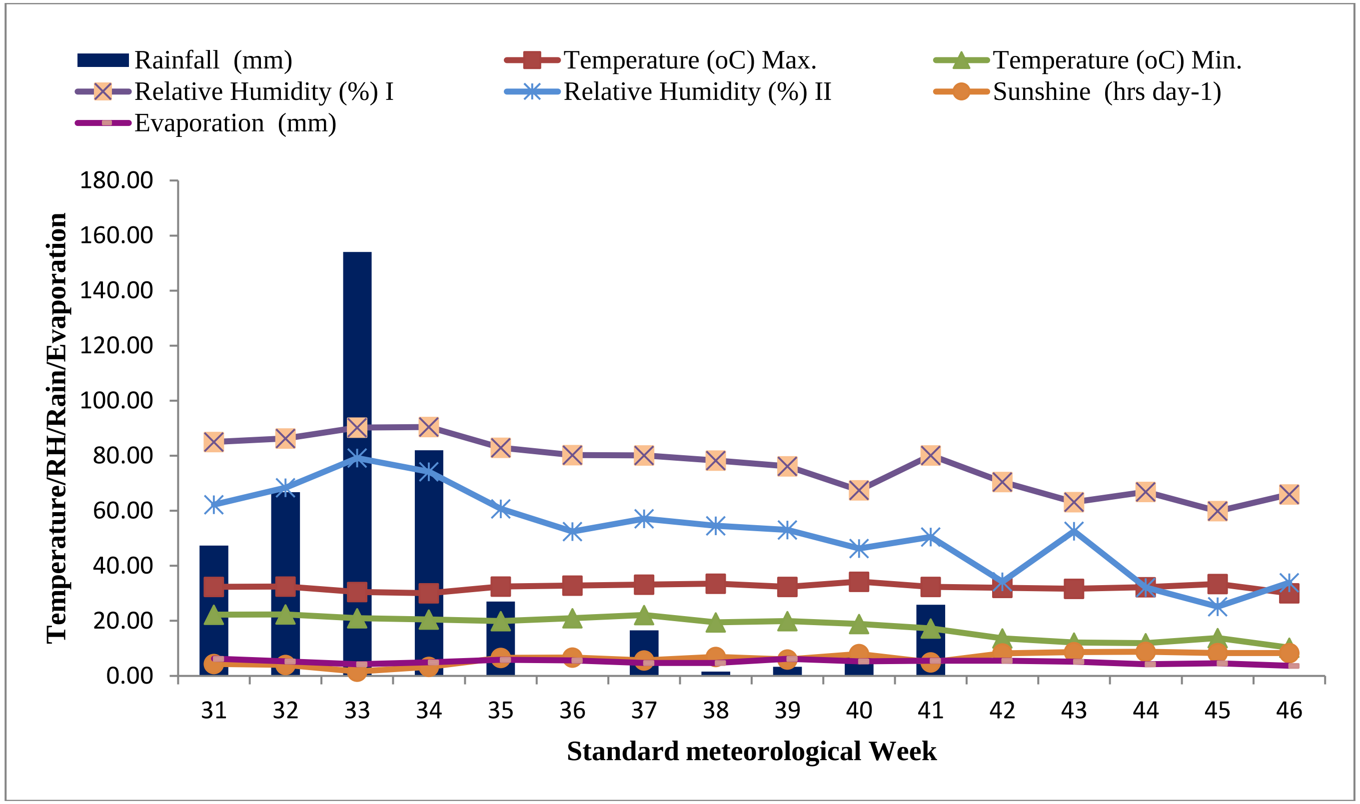

Fig. 1. Detailed Mean weekly meteorological data during crop growing season

Table 1. The experiment comprised twelve treatments combinations are given below

	Treatments Details
T_1	Atrazine 50% WP @ 0.50 kg *a.i* ha^{-1} as pre- emergence (PE)
T_2	Metolachlor 50% EC @ 1.00 kg *a.i* ha^{-1} as PE
T_3	Pyroxasulfone 85% w/w WG @ 0.1275 kg *a.i* ha^{-1} as PE
T_4	2,4-D Na Salt 80% WP @ 0.75 kg *a.i*. ha^{-1} as post- emergence (PoE) at 20 DAS
T_5	T_1 + Atrazine 50% WP @ 0.50 kg *a.i.* ha^{-1} as (PoE)
T_6	T_1 + 2,4-D Na Salt 80% WP @ 0.75 kg *a.i.* ha^{-1} ha as PoE at 20 DAS
T_7	Intercropping with cowpea (1:1 additive series) without herbicides
T_8	Intercropping with cowpea (1:1 additive series) + Pendimethalin 30% EC @ 0.75 kg *a.i*. ha^{-1} as PE
T_9	Intercropping with blackgram (1:1 additive series) without herbicides
T_{10}	Intercropping with blackgram (1:1 additive series) + Pendimethalin 30% EC @ 0.75 kg *a.i.* ha^{-1} as PE
T_{11}	Weed free (Two hand weeding at 15 and 35 DAS)
T_{12}	Weedy check

Table 2. Details of herbicide profiles

S. No.	Common name	Trade name	Chemical name
1.	Atrazine	Solaro 50	1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine
2.	Metolachlor	Amicus	2-chloro-N-(2-ethyl-6-methylphenyl)-N-(1-methoxypropan-2-yl) acetamide.
3.	Pyroxasulfone	Momiji® Pyroxasulfone 85% WG;	3-{[5-(Difluoromethoxy)-1-methyl-3-(trifluoromethyl)-1H-pyrazol-4-yl]methanesulfonyl}-5,5-dimethyl-4,5-dihydro-1,2-oxazole
4.	2,4-D Na Salt	Suspend	(2,4-Dichlorophenoxy)acetic acid
5.	Pendimethalin	Stomp 30 EC	N-(1-ethylpropyl)-2,6-dinitro-3,4-xylidine

2.3 Agronomical Practices

The experimental field was meticulously prepared to ensure optimal conditions for crop establishment. Initial tillage was carried out using a tractor-mounted disc plough, which helped in inverting the soil, burying weeds, and incorporating residual organic matter. The field was then kept fallow during the summer months, a practice that facilitated natural soil aeration and aided in the conservation of residual moisture, particularly important under the rainfed conditions typical of South-West Rajasthan. With the onset of the monsoon, the field underwent secondary tillage operations, including cross-harrowing to break down soil clods and enhance tilth, followed by planking to level the land and preserve soil moisture, ultimately creating a fine, well-structured seedbed conducive for uniform germination. Fertilization was done based on standard agronomic recommendations for sorghum, with a basal dose of 80 kg nitrogen, 40 kg phosphorus (P_2O_5), and 40 kg potassium (K_2O) per hectare. To support the nutrient demands of the intercropped legumes, additional phosphorus was applied. The cropping system involved sorghum intercropped with cowpea variety ‘Dollar’ and black gram variety ‘Kota Urd-3’ in a 1:1 additive series. This arrangement allowed for efficient use of resources, with an intra-row spacing of 5 cm to ensure proper plant density and minimize competition. Weed management included both chemical and manual methods. Pre-emergence and post-emergence herbicides were applied using a manually operated foot sprayer equipped with a flat fan nozzle, ensuring uniform application at a spray volume of 500 liters per hectare. In manually weeded plots, hand weeding was performed twice, at 15 and 35 days after sowing (DAS), to maintain a weed-free environment during critical crop growth stages. For pest control, two applications of lambda-cyhalothrin 5% EC, a systemic insecticide, were conducted once a week for 3 weeks at key growth intervals to manage insect pressure effectively. Harvesting was performed at 107 DAS. To ensure accurate yield assessment and eliminate border effects, outer rows and a 0.5-meter buffer zone around each plot were excluded from data collection. This approach helped maintain the integrity of the experimental results and allowed for precise evaluation of treatment effects on sorghum and intercrop performance.

2.4 Observations to be Recorded

2.4.1 Weed flora

Various types of weeds were identified and divided into categories like grasses, sedges and broad- leaved weeds. Species wise classification was also done.

2.4.2 Weed density population

The weeds were counted at 20 days after PE, 40 days after PE and at fodder harvest. The spots were selected randomly in each plot using 0.25 m^{-2} quadrate to mark the area. Separate counts were recorded for total grassy, total broad-leaved and total sedges in square metre area. Total weed population was also calculated by adding total grasses, sedges and broad- leaved weeds. The mean data were subjected to square root transformation $(x + 0.5)^{1/2}$ to normalize their distribution (Gomez and Gomez, 1984).

2.4.3 Weed dry matter

Weeds collected from 0.25 m^{-2} area were uprooted at 20 days after PE, 40 days after PE and at harvest. Then weeds were classified as grassy, broad- leaved and sedges. The samples were sun dried for few days and then oven dried at 70 ºC till a constant weight was observed to obtain weed dry matter. Separate counts for total grassy, total broad- leaved and total sedges were recorded from square metre area. Total weed dry matter was also calculated by adding total grasses, sedges and broad- leaved weeds.

2.4.4 Weed index

The Weed Index is a valuable indicator in sorghum weed management, as it quantifies yield losses due to weed interference and helps evaluate the effectiveness of various control strategies. By identifying treatments that minimize yield reduction, it supports informed decision-making for adopting the most efficient and economically viable weed control methods. Weed Index (fodder yield in comparison to weed free) was calculated by the following formula (Yadav and Mishra, 1982).

$$\text{Weed Index} = \frac{X-Y}{X} \times 100$$

Where, X = Average crop yield in control plot, Y = Average crop yield in treated plot

2.5 Statistical Analysis

The data recorded during the experimental period were statistically analyzed using the Analysis of Variance (ANOVA) technique, following the methodology outlined by Fisher (1950). Treatment effects were evaluated, and the significance of differences among means was determined using the F-test at the 5% probability level. Wherever the F-value indicated statistical significance, further interpretation was carried out to assess treatment performance reliably.

3. RESULTS AND DISCUSSION

3.1 Weed Flora

Kharif season crops are often challenged by a diverse spectrum of weed species, including grasses, broad-leaved weeds, and sedges.

3.2 Weed Population

All the weed management treatments significantly affected the grassy, sedges and broad leaved weeds at 20, 40 and at harvest days after pre- emergence spray (Tables 1-6).

3.2.1 Grasses

The density of grassy weeds (no. m^{-2}) observed at 20 days after PE herbicide application was significantly affected by the various weed management strategies employed, showing notable improvement over the untreated control (weedy check). Among all treatments, the weed-free plots (T_{11}), maintained through manual hand weeding at 15 and 35 days after sowing (DAS), exhibited the lowest grass population due to continuous and complete removal of weeds. Although highly effective, this approach is labor-intensive, less feasible under labor-scarce conditions, and economically unsustainable concerns previously emphasized by Kolage et al. (2004) and Patel et al. (2006). Among herbicide-based treatments, T_5 recorded the minimum density of dominant grassy weeds such as *Digitaria sanguinalis*, *Cynodon dactylon*, and *Echinochloa crus-galli*. This superior control was attributed to the dual application of atrazine, which extended its residual effect and inhibited multiple flushes of weed emergence throughout the crop growth period. Treatment T_2 also suppressed grass populations effectively, although to a lesser extent than T_5, and was significantly better than T_4 and the weedy check. The data taken at 40 days after PE revealed significant differences in weed suppression across treatments, with notable reductions in specific weed species due to the efficacy of certain herbicidal strategies. T_2 was particularly effective in minimizing the population of *Digitaria sanguinalis*, *Echinochloa colona*, and *Dactyloctenium aegyptium*. These reductions were statistically comparable to T_1 and T_5 for *D. sanguinalis*, to T_3 for *E. colona*, and to T_5 for *D. aegyptium*. Similarly, the lowest density of *Echinochloa crus-galli* was recorded under T_2 and T_5, both of which were on par with T_1, suggesting their superior grass-suppressive potential. Treatment T_5 further demonstrated notable efficacy against *Dinebra retroflexa*, recording significantly lower counts than all other treatments. In terms of total grassy weed population, T_5 again outperformed all other management options, indicating the broad-spectrum pre- and post-emergence control provided by sequential atrazine applications. The evaluation of grassy weed populations at harvest under various herbicidal treatments revealed that T_5 consistently outperformed other treatments in reducing a wide spectrum of weed species. Notably, *Zizaniopsis miliacea* showed the highest population suppression under T_5, indicating strong efficacy of sequential atrazine application. Similarly, T_6 (a combination of atrazine as pre-emergence and 2,4-D Na salt as post-emergence) proved most effective in reducing *Dactyloctenium aegyptium*, significantly outperforming all other treatments. In terms of total grassy weed control, T_5 again emerged as the most effective, achieving a 56.62% reduction over the untreated control. While T_3 was statistically comparable for some grass species, T_5 consistently yielded the lowest overall grass density, highlighting its broad-spectrum efficacy.

Table 3. The predominant weed flora observed during the field investigation

S. No.	Botanical name	English name	Type of weed flora
1.	*Commelina benghalensis* L.	Day flower	Broad- leaved weeds
2.	*Convolvulas arvensis* (L.)	Hirankhuri	Broad-leaved weeds
3.	*Cynodon dactylon* (L.) Pear.	Bermuda grass	Grassy

S. No.	Botanical name	English name	Type of weed flora
4.	*Dactyloctenium aegyptium*	Egyptian crowfoot grass	Grassy
5.	*Cyperus rotundus* L.	Purple nutsedge	Sedge
6.	*Amaranthus* spp.	Amaranthus	Broad-leaved weed
7.	*Digera arvensis* (L.)	False amaranth	Broad-leaved weed
8.	*Echinochloa* spp. (L.) Link	Jungle rice	Grassy
9.	*Digitaria sanguinalis*	Crabgrass	Grassy
10.	*Zizanopis miliacea*	Giant cutgrass	Grassy

***Commelina benghalensis* L.**

***Cynodon dactylon* (L.) Pear.**

***Digera arvensis* L.**

Echinochloa colonum

***Cyperus rotundus* L.**

Dactyloctenium aegyptium

Amaranthus viridis

Amaranthus spinosus

Echinochloa crusgalli

Digitaria sanguinalis

Dinebra retroflexa

***Convolvulus arvensis* L.**

Images 1. Photoplates of the weed species taken during the study

3.2.2 Sedges

In the case of sedges at 20 days after PE, particularly *Cyperus rotundus*, T_5 achieved a substantial reduction of 48.58% over the control. At 40 days after PE, in Cyperus *rotundus*, T_5 achieved the most substantial control, with a 74.63% reduction compared to the untreated control, highlighting its effectiveness in targeting resilient perennial weeds. At harvest, *Cyperus rotundus*, a persistent sedge species, T_5 recorded the lowest population, reflecting a 62.39% reduction compared to the weedy check. This superior control underscores the herbicide's sustained activity throughout the growing season.

3.2.3 Broad- leaved weeds

For broad-leaved at 20 days after PE weeds, including *Commelina benghalensis*, T_5 again proved most efficient, with a 35.33% reduction in total broad-leaved weed population compared to the weedy check. This broad-spectrum weed suppression is largely credited to the residual and systemic action of atrazine, applied at both early and later stages of crop development, effectively targeting multiple weed species during critical growth phases. Moreover, atrazine, a herbicide from the triazine group, is widely used for controlling both monocot and dicot weeds. It is a selective herbicide typically applied before weed emergence (pre-emergence) to manage early weed growth. Atrazine accumulates in the chloroplasts of plants, disrupting photosynthesis by interfering with the electron transport near Photosystem II. This disruption hinders the plant’s ability to synthesize food, eventually leading to plant death due to starvation (Gupta, 2008). In the category of broad-leaved weeds at 40 days after PE, *Commelina benghalensis* and *Convolvulus arvensis* were most effectively suppressed by T_6, attributed to the combined action of atrazine PE and 2,4-D Na salt PoE. Also, 2,4-D is classified as a selective systemic herbicide. EPA (2005) explains that 2,4-D kills plants by altering three key factors: it increases the plasticity of the plant’s cell walls, boosts protein production, and raises ethylene production within the plant. These changes lead to uncontrolled cell division and excessive growth, ultimately damaging plant tissues and resulting in the plant's death. *Amaranthus spinosus* was significantly reduced under T_2, with statistically similar suppression seen in T_3, T_5, and T_6. T_4, which involved post-emergence application of 2,4-D Na salt, was effective in reducing other broad-leaved weeds and was statistically comparable to T_5. The maximum overall reduction in broad-leaved weeds (2.86

m^{-2}) was recorded under T_6, representing a 36.86% decrease relative to the weedy check, and was statistically at par with T_2 and T_5. The superior performance of treatments T_5 and T_6 can be attributed to their ability to control a broad spectrum of weeds grasses, sedges, and broad-leaved species through sequential or combined herbicide application, effectively reducing early competition and enhancing crop growth. Among broad-leaved weeds poplution at harvest, both *Amaranthus viridis* and *Amaranthus spinosus* populations were markedly reduced by T_5, with statistically similar results noted in T_2, T_4, T_6, and T_{10} for *A. viridis* and T_1, T_2, T_4, T_6, and T_8 for *A. spinosus*. Interestingly, T_9, involving intercropping with black gram without herbicides, effectively suppressed *Convolvulus arvensis*, and was statistically on par with T_5, suggesting a competitive advantage conferred by legume intercropping. Moreover, T_6 showed the highest reduction in other broad-leaved species and recorded the maximum overall reduction in total broad-leaved weed population, at 37.20% over the weedy check, performing statistically at par with T_4 and T_5. The consistent superiority of T_5 and T_6 across multiple weed types can be attributed to their dual-phase control strategy, combining early-season suppression with sustained post-emergence activity. This integrated approach not only limits weed emergence but also minimizes competition throughout the crop growth period, thereby enhancing sorghum productivity.

3.3 Weed Dry Matter

3.3.1 Grasses

The data on dry matter species wise is illustrated from Table 7 to 13. The effectiveness of various weed management strategies was further confirmed by their impact on dry matter accumulation of dominant weed species. Among grasses, Treatment T_5 consistently recorded the lowest dry matter accumulation for *Digitaria sanguinalis*, *Cynodon dactylon*, and *Echinochloa crus-galli*. These reductions were statistically comparable to those achieved by T_2, T_3, and T_6 in *D. sanguinalis*; T_2, T_3, T_6, and T_8 in *C. dactylon*; and T_2, T_3, T_6, T_7, and T_8 in *E. crusgalli*, indicating a broad efficacy across herbicide combinations. For total grass dry matter, T_2 recorded the lowest values, statistically at par with T_5, suggesting both treatments are highly effective in suppressing grassy weed biomass during critical crop growth stages. Additionally, T_{10} also showed significant suppression of other minor grass species, showcasing the contribution of diverse approaches. In case of dry matter accumulation of weed species at 40 days after PE reveals that among the grassy weeds like *Digitaria sanguinalis*, *Echinochloa crusgalli*, *Echinochloa colona*, and *Dactyloctenium aegyptium*. Treatment T_2 achieved the lowest dry matter accumulation, indicating high suppression efficacy. Specifically, T_2 was statistically comparable to T_1 and T_9 for *E. crusgalli*, and on par with T_3, T_5, and T_6 in controlling *D. aegyptium*, reinforcing its broad-spectrum control. Furthermore, T_5 proved particularly effective in reducing biomass of *Dinebra retroflexa*, with its performance statistically at par with T_2 and T_6. The lowest accumulation of miscellaneous grassy weeds was observed under T_{10}, which also performed similarly to T_1, T_3, T_7, T_8, and T_9, suggesting the importance of diverse treatment strategies.

When considering total grass dry matter, T_5 again stood out by recording significantly lower accumulation compared to the untreated control. This result was statistically on par with T_1, T_2, T_3, T_6, and T_8, showcasing its consistent effectiveness across multiple weed categories. The effectiveness of various weed management treatments was found evident at harvest from their impact on dry matter accumulation across different weed categories. The minimum dry matter accumulation of *Zizanopsis miliacea* was observed under Treatment T_5, with performance statistically comparable to T_3 and T_8, reflecting its robust suppressive action. For *Dactyloctenium aegyptium*, the lowest biomass was recorded under T_6, followed closely by T_5, indicating both treatments' effective control of this species. In the case of other grasses, T_3 showed the most significant reduction in dry matter accumulation, statistically at par with T_1, reinforcing its potential in grass weed suppression. When considering total grass biomass, T_5 again emerged as the most effective, outperforming all other treatments and being statistically similar to T_3. The percent reduction in total grassy weed dry matter due to T_5 was 64.76%, compared to 58.71% for T_3, relative to the weedy check, reflecting its superior efficiency.

3.3.2 Sedges

Assessment of dry matter accumulation of *Cyperus rotundus,* notoriously resilient sedge at 20 days after PE, T_5 once again achieved the lowest dry matter accumulation, closely followed by T_6. These treatments reduced sedge biomass by 88.88% and 83.33%, respectively, over the weedy control, highlighting their superior and consistent suppression potential throughout the growing season. At 40 days after PE, T_5 recorded the lowest dry matter accumulation, achieving a 65.07% reduction over the weedy check. This was closely followed by T_2 and T_3, with reductions of 56.46% and 60.00%, respectively, highlighting their strong potential in sedge suppression. At harvest, agin T_5 recorded the lowest dry matter accumulation, statistically comparable with T_2, T_3, and T_6. Notably, the dry matter reduction in this species by T_5 reached 74.87%, underscoring its high herbicidal efficacy.

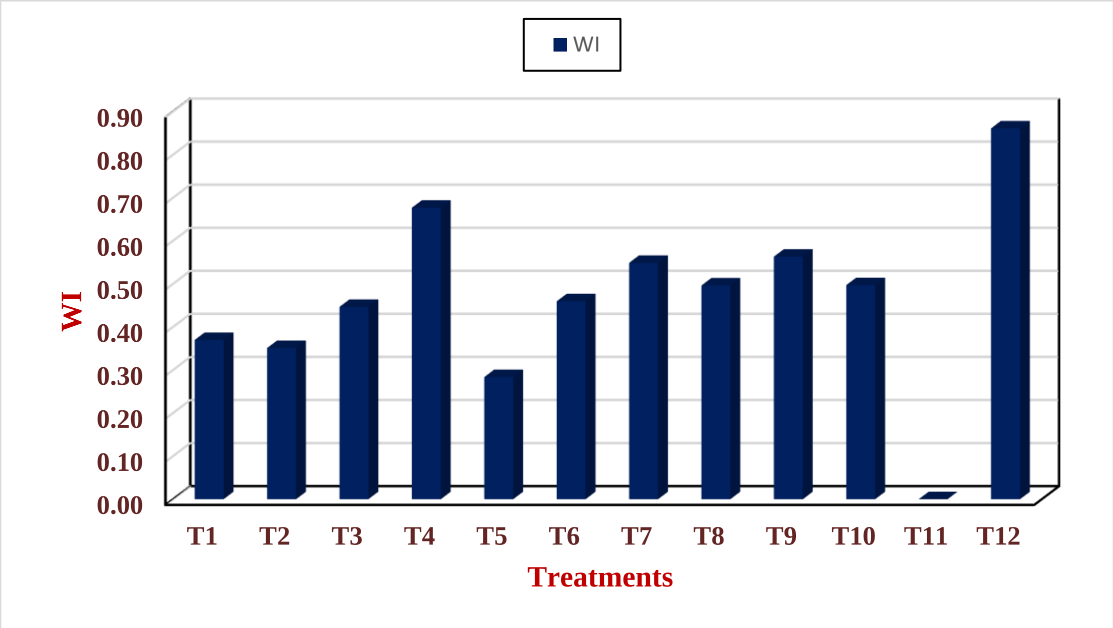

Fig. 2. Effect of weed management on WI

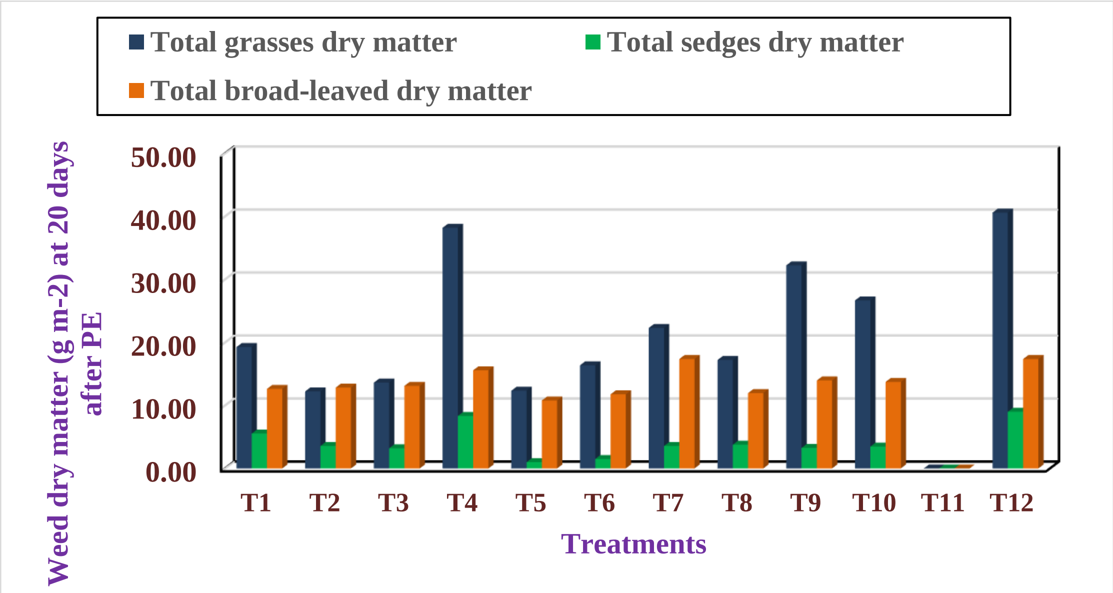

Fig. 3. Effect of weed management on weed dry matter (g m^{-2}) at 20 days after PE

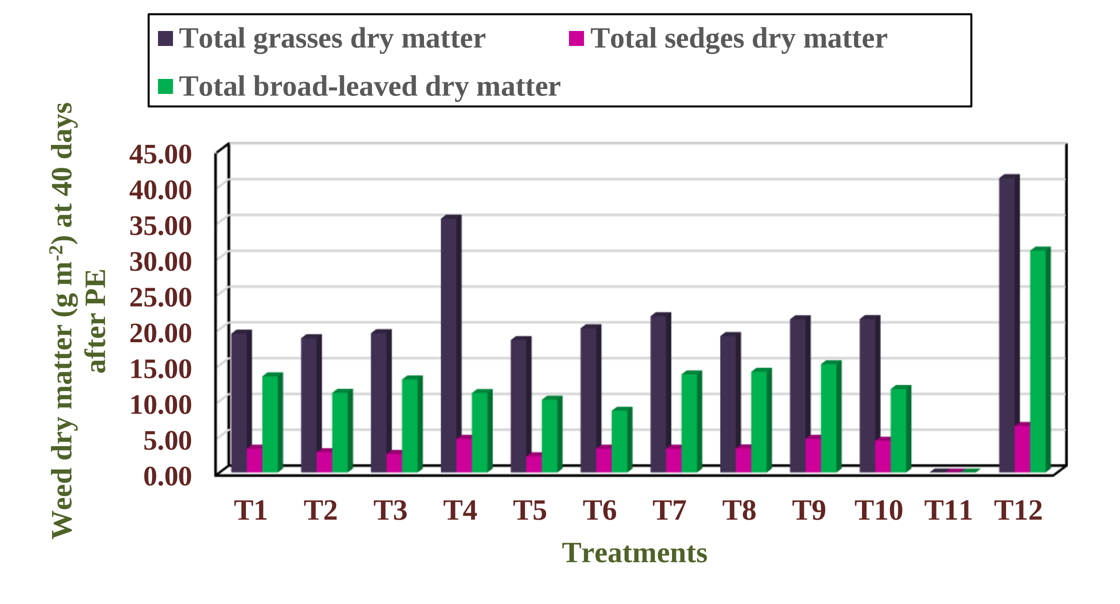

Fig. 4. Effect of weed management on weed dry matter (g m^{-2}) at 40 days after PE

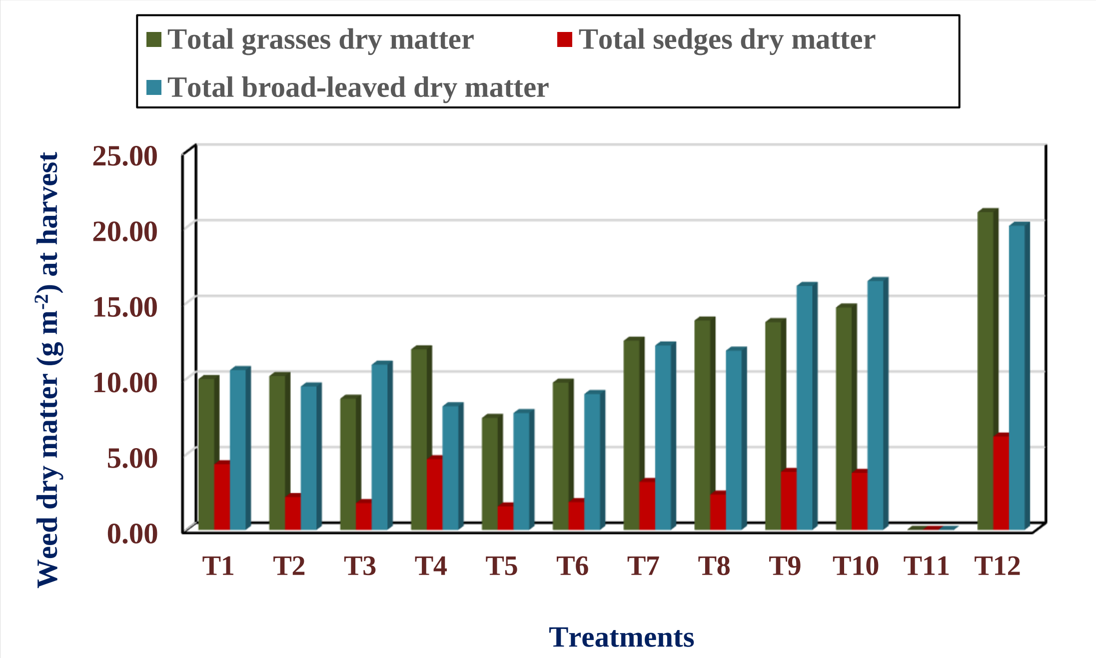

Fig. 5. Effect of weed management on weed dry matter (g m^{-2}) at harvest

3.3.3 Broad- leaved weeds

In terms of broad-leaved weed species, at 20 days after PE, dry matter of *Commelina benghalensis* was most effectively reduced by T_2 and T_5, which were statistically on par with T_1, T_3, and T_6. Similarly, *Digera arvensis* recorded significantly lower biomass under T_5, which was comparable with T_6. Total broad-leaved weed biomass was minimized under T_5, with T_6 and T_8 also showing comparable effectiveness, and all three were statistically superior to the rest of the treatments. Overall, the outstanding performance of T_5 can be attributed to its dual-mode action providing early and extended control through sequential herbicide application. This approach effectively limits weed growth, reduces competition for resources, and ultimately contributes to improved crop performance. The high efficacy of T_6 and T_2 further highlights the advantage of combining or sequencing herbicides with complementary modes of action for broader and more sustained weed suppression.

At 40 days after PE, dry matter accumulation in broad-leaved weeds, again showed that T_5 was also highly effective in minimizing biomass accumulation in *Amaranthus viridis*, *Amaranthus spinosus*, and *Convolvulus arvensis*. Its performance was statistically similar to that of T_1, T_2, T_4, and T_{10} for *A. viridis*; T_2, T_4, and T_6 for *C. arvensis*; and T_4 and T_6 for *A. spinosus*. Furthermore, T_4 was notably efficient in reducing dry matter accumulation in miscellaneous broad-leaved weeds, with effects statistically at par with T_3, T_5, T_6, T_7, and T_9. Overall, T_5 demonstrated the lowest total dry matter accumulation of broad-leaved weeds, significantly outperforming most other treatments. It was statistically on par with T_4 and T_6, indicating its consistency across weed categories. The percent reduction in total broad-leaved weed biomass was 61.59% under T_5, compared to 59.35% and 55.32% for T_4 and T_6, respectively, when compared to the weedy check. These results collectively affirm that T_5, involving the application of Atrazine 50% WP and likely a follow-up post-emergent herbicide, delivered the most comprehensive and consistent weed suppression across all major weed groups grasses, sedges, and broad-leaved species making it the most effective and reliable treatment under the tested conditions. The dry matter accumulation of the entire weed species follows a similar trend to that of the weed population at each observation stage.

3.4 Weed Index

The minimum weed index was observed in the weed-free plots managed through two manual hand weedings at 15 and 35 DAS, indicating the highest crop productivity due to complete weed suppression. Among the herbicidal treatments, the lowest weed index of 0.28% was recorded under the application of atrazine 50% WP (T_5), which was statistically comparable with T_1 (0.37%) and T_2 (0.35%). The reduced weed index under these treatments reflects their effectiveness in minimizing weed competition, thereby maximizing sorghum yield The Fig. 2 represents effect of weed management on weed index.

3.5 Productivity

The data on green fodder yield presented in Fig. 7. show that green fodder yield was significantly influenced by weed management. Significantly maximum green fodder yield (69620 kg ha^{-1}) was obtained in T_{11} and it was superior over rest of the treatments. Among weed control treatments, higher green fodder yield was recorded under T_5 and it was also superior over rest of the treatment. The increase in green fodder yield due to application of T_5 was 54.66, 41.49, 82.11, 209.39, 93.28, 126.77, 96.48, 130.70 and 106.74 per cent in comparison to T_1, T_2, T_3, T_4, T_6, T_7, T_8, T_9 and T_{10}, respectively. This outcome was attributed to a weed-free environment maintained until harvest, which minimized competition for essential growth resources such as light, space,

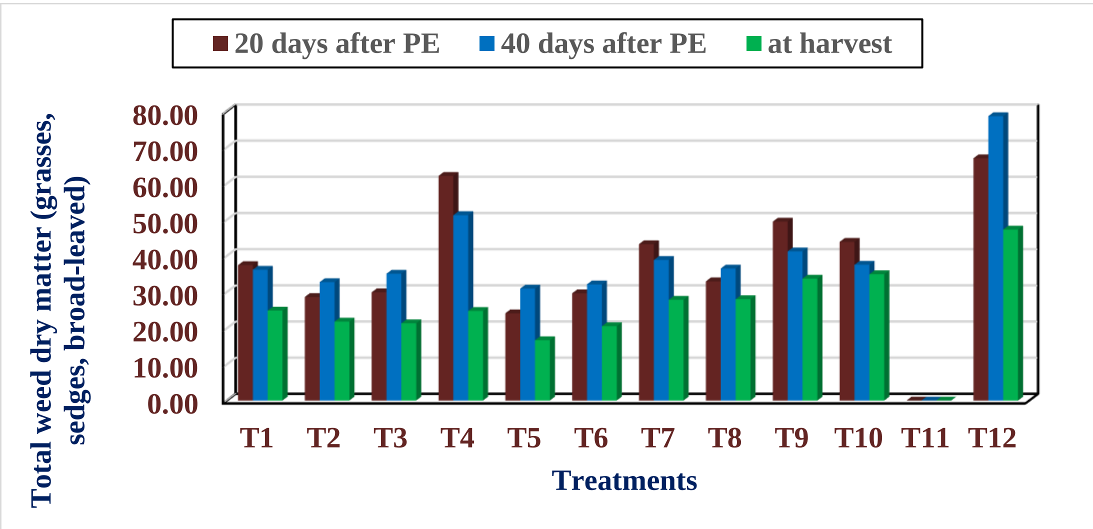

Fig. 6. Effect of weed management on total (grasses, sedges and broad- leaved) weed dry matter (g m^{-2})

Table 4. Effect of weed management on weed population (grasses and sedges) at 20 days after PE

Treatments	Weed population (No.m^{-2})					
	Grasses					Sedges
	Digitaria sanguinalis	***Cynodon dactylon***	***Echinocloa crusgalli***	**Other grasses**	**Total grasses**	***Cyperus rotundus***
T_1	3.34(1.94)	2.33(1.68)	2.00(1.5)	3.33(1.95	11.0(3.38)	7.00(2.68)
T_2	2.33(1.64)	1.00(1.22)	1.33(1.34)	3.33(1.93)	8.00(2.89)	4.33(2.16)
T_3	3.00(1.86)	1.00(1.17)	0.67(1.05)	3.33(1.95)	8.00(2.91)	3.00(1.86)
T_4	3.67(2.04)	3.33(1.90)	3.00(1.87)	8.33(2.97)	18.33(4.34)	8.00(2.92)
T_5	1.33(1.34)	0.67(1.05)	0.67(1.00)	3.33(1.94)	6.00 (2.53)	2.33(1.64)
T_6	3.00 (1.79)	1.00(1.22)	1.33(1.35)	4.34(2.17)	9.67(3.16)	3.00 (1.87)
T_7	3.33(1.94)	1.67(1.46)	2.00(1.58)	5.00(2.30)	12.00(3.50)	6.00 (2.54)
T_8	3.33(1.94)	1.33(1.34)	1.67(1.46)	3.67(2.02)	10.00 (3.21)	6.33(2.60)
T_9	4.67(2.27)	3.00(1.87)	2.67(1.77)	3.33(1.95)	13.67 (3.76)	3.33(1.95)
T_{10}	3.67(2.04)	2.67(1.77)	2.67(1.76)	3.67(2.04)	12.67(3.62)	4.00 (2.12)
T_{11}	0.00 (0.71)	0.00 (0.71)	0.00(0.71)	0.00(0.71)	0.00(0.71)	0.00(0.71)
T_{12}	6.67(2.67)	5.33(2.41)	3.33(1.96)	9.33(3.13)	24.67 (5.02)	9.67 (3.19)
SEm$\pm$	0.17	0.15	0.13	0.16	0.20	0.19
CD(P=0.05)	0.50	0.45	0.38	0.46	0.60	0.55

*Note: Figures in parentheses are transformed values i.e., $\sqrt{(X+0.5)}$ and *original value*

Table 5. Effect of weed management on weed population (broad- leaved) at 20 days after PE

Treatments	Weed population (No.m^{-2})			
	Broad-leaved			
	Commelina benghalensis	***Digera arvensis***	**Other broad-leaved**	**Total broad-leaved**
T_1	3.00*1.87)	1.67 (1.46)	4.33 (1.95)	9.67(3.13)
T_2	0.67 (1.05)	0.33 (0.88)	8.00 (2.90)	9.00(3.08)
T_3	0.67(1.05)	0.33 (0.88)	8.67 (3.03)	9.67 (3.18)
T_4	5.00(2.35)	3.00 (1.87)	12.00 (3.53)	20.00 (4.53)
T_5	0.33 (0.88)	0.33 (0.88)	8.00 (2.90)	8.67 (3.02)
T_6	0.67 (1.05)	0.33 (0.88)	7.67 (2.85)	9.00 (3.07)
T_7	1.67 (1.46)	1.33 (1.35)	10.34 (3.29)	13.33(3.72)
T_8	0.66 (1.08)	0.66 (1.08)	11.01 (3.39)	12.33 (3.58)
T_9	3.67 (2.04)	2.67 (1.77)	11.00 (3.35)	17.33 (4.21)
T_{10}	3.33 (1.95)	2.33 (1.68)	8.34 (2.96)	14.00 (3.80)
T_{11}	0.00(0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
T_{12}	5.33 (2.41)	4.00 (2.12)	12.00 (3.53)	21.33(4.67)
SEm$\pm$	0.12	0.10	0.25	0.16
CD(P=0.05)	0.35	0.30	0.74	0.47

*Note: Figures in parentheses are transformed values i.e., $\sqrt{(X+0.5)}$ and*original value*

Table 6. Effect of weed management on weed population (grasses) at 40 days after PE

Treatments	Weed population (No.m^{-2})						
	Grasses						
	Digitaria sanguinalis	***Echinocloa crusgalli***	***Echinocloa colonum***	***Dactylopteium aegyptium***	***Dinebra retroflexa***	**Other grasses**	**Total grasses**
T_1	0.33* (0.91)	0.67(1.05)	5.00(2.35)	2.00(1.58)	11.67(3.49)	1.11(1.22	20.7(4.61)
T_2	0.30 (0.89)	0.33(0.	0.00(0.71)	0.89(1.14)	3.33(1.94)	4.49(2.21	9.34(3.11)
T_3	0.60(1.05)	6.00(2.5)	0.33(0.88)	1.67(1.46)	14.67(3.88)	1.73(1.38	25.00(5.04)
T_4	1.50 (1.41)	8.33(2.9)	18.33(4.34)	8.00(2.91)	18.00(4.30)	2.67(1.76	56.83(7.57)
T_5	0.33 (0.91)	0.33(0.8)	0.66(1.08)	1.67(1.22)	0.00(0.71)	1.67(1.45	3.99(2.11)
T_6	0.67 (1.08)	6.67(2.67)	1.00(1.22)	2.00(1.58)	1.00(1.22)	4.0(2.12)	15.33(3.98)
T_7	1.00(1.22)	8.33(2.97)	2.00(1.58)	2.67(1.77)	6.67(2.66)	3.34(1.9)	24.00 (4.95)
T_8	1.00(1.22)	5.00(2.5)	2.00(1.58)	2.33(1.68)	3.67(2.04)	3.00(1.86	17.00(4.18)
T_9	1.25(1.32)	2.00(1.58)	2.67(1.76)	2.67(1.77)	3.67(2.02)	5.42(2.43	17.67(4.25)
T_{10}	1.33(1.35)	2.33(1.68)	2.33(1.64)	5.33(2.41)	3.33(1.95)	3.00(1.8)	17.67(4.26)
T_{11}	0.00(0.71)	0.00(0.71)	0.00(0.71)	0.00(0.71)	0.00(0.71)	0.00(0.7)	0.00(0.7)
T_{12}	6.00 (2.55)	18.00(4.3)	25.33(5.08)	13.33(3.72)	18.67(4.38)	6.33(2.60	87.67(9.39)
SEm$\pm$	0.03	0.10	0.12	0.11	0.12	0.19	0.15
CD(P=0.05)	0.09	0.31	0.34	0.31	0.36	0.55	0.45

*Note: Figures in parentheses are transformed values i.e., √(X+0.5) and *original value*

Table 7. Effect of weed management on weed population (broad- leaved and sedges) at 40 days after PE

Treatments	Weed population (No.m^{-2})						
	Broad- leaved						Sedges
	Amaranthus spinosus	***Amaranthus viridis***	***Commelina benghalensis***	***Convolvulus arvensis***	**Other broad-leaved**	**Total broad-leaved**	***Cyperus rotundus***
T_1	3.00*(1.86)	2.67(1.77)	1.67(1.46)	2.00(1.58)	3.00 (1.86)	12.33(3.58)	2.67(1.76)
T_2	1.33(1.29)	1.67(1.46)	1.00(1.22)	1.33(1.35)	3.00(1.84)	8.33(2.95)	1.33(1.29)
T_3	2.33(1.68)	1.33(1.27)	1.00(1.22)	1.33(1.34)	4.67(2.26)	10.6(3.34)	1.00(1.22)
T_4	4.00(2.10)	3.00(1.87)	1.33(1.34)	1.00(1.17)	1.00(1.17)	10.33(3.28)	12.67(3.62)
T_5	1.33(1.34)	1.33(1.34)	2.33(1.68)	1.00(1.22)	2.00(1.56)	8.00(2.92)	0.67(1.05)
T_6	2.33(1.68)	1.33(1.34)	0.64(1.07)	0.67(1.00)	2.69(1.78)	7.67(2.86)	2.00(1.58)
T_7	3.67(2.02)	2.33(1.68)	2.00(1.58)	1.67(1.46)	4.00(2.11)	13.6(3.76)	5.6(2.47)
T_8	3.00(1.86)	2.33(1.66)	1.00(1.22)	1.67(1.46)	3.67(2.02)	11.67(3.49)	3.67(2.02)
T_9	4.00(2.12)	2.66(1.77)	2.67(1.77)	2.33(1.66)	4.11(2.15)	15.78(4.03)	4.67(2.27)
T_{10}	3.33(1.95)	2.33(1.68)	1.67(1.46)	1.97(1.57)	2.69(1.78)	12.00(3.53)	5.00(2.29)
T_{11}	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)
T_{12}	4.33(2.20)	4.00(2.12)	3.67(2.02)	3.00(1.86)	5.00(2.34)	20.00(4.53)	16.67(4.14)
SEm$\pm$	0.16	0.14	0.09	0.14	0.16	0.13	0.17
CD(P=0.05)	0.47	0.42	0.26	0.42	0.47	0.38	0.50

*Note: Figures in parentheses are transformed values i.e., √(X+0.5) and*original value*

Table 8. Effect of weed management on weed population (grasses and sedges) at harvest

Treatments	Weed population (No.m^{-2})				
	Grasses				Sedges
	Zizanopis miliacea	***Dactylotecium aegypticum***	**Other grasses**	**Total grasses**	***Cyperus rotundus***
T_1	4.00*(2.12)	2.33(1.68)	3.33(1.94)	9.67(3.19)	3.67(2.04)
T_2	2.00(1.58)	2.00(1.58)	7.00((2.73)	11.00(3.38)	2.33(1.68)
T_3	2.00(1.58)	5.0 (2.34)	1.67(1.25)	8.67(3.00)	1.00(1.22)
T_4	4.00(2.12)	4.00(2.12)	5.67(2.43)	13.67(3.75)	2.67(1.77)
T_5	1.33(1.34)	2.33(1.68)	1.00(1.22)	4.67(2.26)	0.33(0.88)
T_6	2.67(1.77)	1.33(1.34)	6.67(2.67)	10.67(3.34)	1.33(1.34)
T_7	3.33(1.94)	4.33(2.20)	9.67(3.19)	17.33(4.22)	2.33(1.68)
T_8	2.33(1.64)	2.00(1.58)	10.00(3.24)	14.33(3.85)	2.00(1.58)
T_9	4.33(2.16)	4.0 (2.12)	11.33(3.44)	19.67(4.49)	2.33(1.68)
T_{10}	2.33(1.68)	2.00(1.58)	10.67(3.34)	15.00(3.94)	2.67(1.77)
T_{11}	0.00(0.71)	0.0 (0.71)	0.00(0.71)	0.00(0.71)	0.00(0.71)
T_{12}	9.00(3.08)	5.00(2.34)	12.67(3.62)	26.67(5.21)	4.67(2.34)
SEm$\pm$	0.13	0.08	0.22	0.15	0.10
CD(P=0.05)	0.39	0.23	0.64	0.43	0.30

*Note: Figures in parentheses are transformed values i.e., $\sqrt{(X+0.5)}$ and *original value*

Table 9. Effect of weed management on weed population (broad- leaved) at harvest

Treatments	Weed population (No.m^{-2})				
	Broad- leaved				
	Amaranthus viridis	***Convolvulus arvensis***	***Amaranthus spinosus***	**Other broad-leaved**	**Total broad-leaved**
T_1	2.00*(1.58)	5.00(2.34)	3.33(1.95)	4.00(2.11)	14.3(3.85)
T_2	1.67(1.46)	5.67(2.45)	3.33(1.95)	4.33(2.19)	15.00(3.93)
T_3	3.67(2.04)	6.00(2.53)	4.00(2.12)	4.33(2.20)	18.00(4.29)
T_4	1.33(1.34)	4.33(2.16)	2.67(1.78)	3.00(1.87)	11.33(3.43)
T_5	1.00(1.17)	3.33(1.94)	2.33(1.64)	6.00(2.55)	12.67(3.62)
T_6	1.67(1.44)	4.00(2.12)	3.33(1.95)	2.17(1.63)	11.17(3.41)
T_7	4.33(2.19)	5.33(2.41)	4.00(2.12)	4.00(2.11)	17.67(4.26)
T_8	2.17(1.63)	4.67(2.26)	3.00(1.87)	6.50(2.64)	16.33(4.10)
T_9	3.50(2.00)	2.00(1.58)	3.67(2.02)	6.83(2.71)	16.00(4.06)
T_{10}	2.00(1.56)	6.00(2.54)	4.00(2.11)	3.33(1.94)	15.33(3.97)
T_{11}	0.00(0.71)	0.00(0.71)	0.00(0.71)	0.00(0.71)	0.00(0.71)
T_{12}	6.33(2.61)	8.33(2.96)	6.00(2.55)	8.33(2.96)	29.00(5.43)
SEm$\pm$	0.14	0.18	0.12	0.12	0.12
CD(P=0.05)	0.40	0.52	0.34	0.34	0.36

*Note: Figures in parentheses are transformed values i.e., $\sqrt{(X + 0.5)}$ and *original value*

Table 10. Effect of weed management on weed dry matter (grasses and sedges) at 20 days after PE

Treatments	Weed dry matter (g m^{-2})					
	Grasses					Sedges
	Digitaria sanguinalis	***Cynodon dactylon***	***Echinooa crusgalli***	**Other grasses**	**Total grasses**	***Cyperus rotundus***
T_1	4.50	5.47	4.33	4.97	19.27	5.53
T_2	3.23	1.37	1.60	6.03	12.23	3.57
T_3	3.50	1.13	1.60	7.40	13.63	3.20
T_4	8.40	7.30	7.17	15.33	38.20	8.33
T_5	2.27	0.93	1.43	7.70	12.33	1.00
T_6	3.67	1.17	1.70	9.83	16.37	1.50
T_7	4.90	2.37	2.00	13.03	22.30	3.57
T_8	5.33	1.47	2.08	8.33	17.22	3.77
T_9	20.07	4.37	7.13	0.67	32.23	3.27
T_{10}	15.73	4.37	5.93	0.63	26.67	3.47
T_{11}	0.00	0.00	0.00	0.00	0.00	0.00
T_{12}	22.07	9.60	7.53	1.39	40.60	9.00
SEm$\pm$	0.50	0.29	0.29	0.66	0.73	0.33
CD (P=0.05)	1.46	0.85	0.86	1.94	2.15	0.96

Table 11. Effect of weed management on weed dry matter (broad-leaved) at 20 days after PE

Treatments	Weed dry matter (gm^{-2})			
	Broad- leaved			
	Commelina benghalensis	***Digera arvensis***	**Other broad-leaved**	**Total broad-leaved**
T_1	1.63	4.97	6.03	12.63
T_2	1.37	2.80	8.67	12.83
T_3	1.63	4.00	7.47	13.10
T_4	5.00	6.43	4.13	15.57
T_5	1.37	2.67	6.75	10.78
T_6	2.00	2.80	6.97	11.77
T_7	3.77	4.43	9.17	17.37
T_8	3.77	4.13	4.07	11.97
T_9	4.17	5.47	4.33	13.97
T_{10}	4.17	4.87	4.70	13.73
T_{11}	0.00	0.00	0.00	0.00
T_{12}	8.23	6.70	2.43	17.37
SEm±	0.24	0.33	0.40	0.49
CD (P=0.05)	0.70	0.96	1.18	1.44

Table 12. Effect of weed management on weed dry matter (grasses) at 40 days after PE

Treatments	Weed dry matter (g m^{-2})						
	Grasses						
	Digitaria sanguinalis	***Echinocloa crusgalli***	***Echinocloa colonum***	***Dactylopteium aegyptium***	***Dinebra retroflexa***	**Others grasses**	**Total grasses**
T_1	2.93	3.20	5.20	2.33	3.27	2.47	19.40
T_2	1.67	3.10	1.17	1.57	2.27	9.00	18.77
T_3	5.33	4.67	2.20	1.67	4.00	1.60	19.47
T_4	5.87	6.10	6.10	4.20	4.33	8.87	35.47
T_5	3.00	3.10	2.20	1.60	1.67	6.93	18.50
T_6	4.67	5.00	3.23	2.03	2.00	3.22	20.15
T_7	5.07	5.50	3.60	3.00	3.27	1.40	21.84
T_8	4.70	4.53	3.27	2.47	2.83	1.26	19.06
T_9	5.33	3.83	4.37	3.33	3.33	1.20	21.40
T_{10}	5.20	4.33	4.13	3.33	3.47	0.97	21.43
T_{11}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_{12}	7.47	9.87	6.17	5.33	4.80	7.50	41.13
SEm$\pm$	0.30	0.33	0.29	0.22	0.26	0.32	0.80
CD (P=0.05)	0.89	0.96	0.85	0.64	0.76	0.93	2.36

Table 13. Effect of weed management on weed dry matter (broad-leaved and sedges) at 40 days after PE

Treatments	Weed dry matter (g m^{-2})						
	Broad-leaved						Sedges
	Amaranthus spinosus	***Amaranthus viridis***	***Commelina benghalensis***	***Convolvulus arvensis***	**Others broad-leaved**	**Total broad-leaved**	***Cyperus rotundus***
T_1	3.07	1.67	4.33	3.00	1.37	13.43	3.33
T_2	1.87	2.83	2.73	1.83	1.87	11.13	2.83
T_3	2.50	1.67	2.53	1.83	4.47	13.00	2.60
T_4	4.33	1.67	2.17	1.50	1.43	11.10	4.70
T_5	1.80	1.33	2.67	1.67	2.70	10.17	2.27
T_6	2.00	1.83	1.67	0.40	2.73	8.63	3.33
T_7	4.00	1.57	3.67	2.00	2.47	13.70	3.33
T_8	3.50	2.33	2.17	1.83	4.23	14.07	3.37
T_9	2.50	2.17	4.33	3.13	3.00	15.13	4.70
T_{10}	3.67	2.33	2.67	2.33	0.67	11.67	4.43
T_{11}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_{12}	7.00	6.33	5.37	4.67	7.63	31.00	6.50
SEm±	0.27	0.21	0.23	0.17	0.17	0.34	0.23
CD (P=0.05)	0.78	0.61	0.67	0.51	0.49	1.01	0.68

Table 14. Effect of weed management on weed dry matter (grasses and sedges) at harvest

Treatments	Weed dry matter (g m^{-2})				
	Grasses				Sedges
	Zizanopis miliacea	***Dactylotecium aegypticum***	**Other grasses**	**Total grasses**	***Cyperus rotundus***
T_1	3.60	3.87	2.50	9.97	4.33
T_2	3.67	2.33	4.17	10.17	2.17
T_3	2.67	4.67	1.33	8.67	1.77
T_4	3.83	4.93	3.17	11.93	4.67
T_5	1.83	1.17	4.40	7.40	1.55
T_6	3.33	1.07	5.33	9.73	1.83
T_7	3.33	4.33	4.83	12.50	3.17
T_8	2.67	3.17	8.00	13.83	2.33
T_9	4.50	3.90	5.33	13.73	3.83
T_{10}	2.70	3.00	9.00	14.70	3.77
T_{11}	0.00	0.00	0.00	0.00	0.00
T_{12}	6.13	6.00	8.87	21.00	6.17
SEm$\pm$	0.29	0.22	0.40	0.58	0.25
CD (P=0.05)	0.86	0.65	1.17	1.69	0.73

Table 15. Effect of weed management on weed dry matter (broad- leaved) at harvest

Treatments	Weed dry matter (g m^{-2})				
	Broad-leaved				
	Amaranthus viridis	***Convolvulus arvensis***	***Amaranthus spinosus***	**Other broad-leaved**	**Total broad-leaved**
T_1	2.33	3.07	2.30	2.86	10.56
T_2	2.30	2.50	2.17	2.51	9.47
T_3	3.17	3.37	2.17	2.22	10.92
T_4	2.23	2.33	2.03	1.57	8.17
T_5	1.77	2.17	1.57	2.22	7.72
T_6	2.63	2.50	1.67	2.18	8.98
T_7	3.67	4.17	2.33	2.02	12.18
T_8	2.63	3.80	2.83	2.58	11.84
T_9	3.07	5.50	5.87	1.69	16.13
T_{10}	2.20	3.50	3.67	7.08	16.45
T_{11}	0.00	0.00	0.00	0.00	0.00
T_{12}	5.30	5.83	5.97	3.00	20.10
SEm$\pm$	0.23	0.27	0.18	0.26	0.51
CD (P=0.05)	0.68	0.79	0.51	0.76	1.48

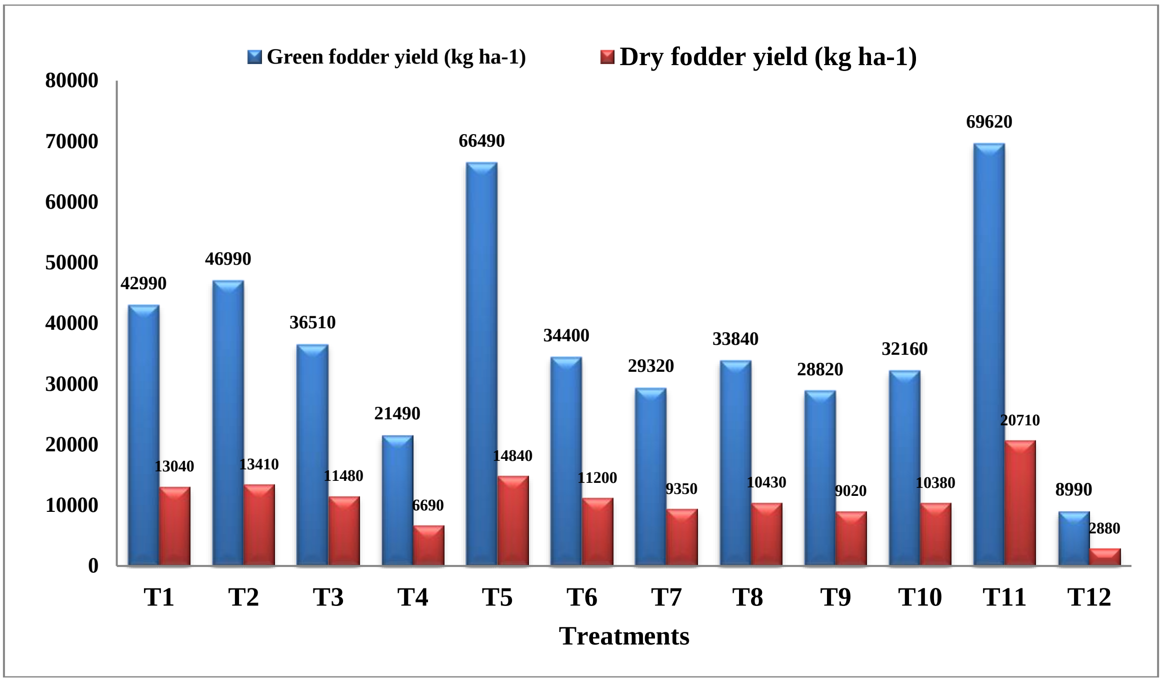

Fig. 7. Effect of weed management on green fodder yield and dry fodder yield (kg ha^{-1})

water, and nutrients. According to Dhar et al. (2006), cultural methods of weed control are also effective in managing weeds without harming the environment. It is a well-established fact that minimizing crop-weed competition during critical growth stages plays a key role in enhancing yield formation by ensuring better access to vital resources for the crop. Dry fodder yield presented in Table 14 and Fig. 7. reveal that higher dry fodder yield (20710 kg ha^{-1}) was obtained under T_{11} which was significantly superior over rest of the treatments. Among weed control treatments, higher dry fodder yield was recorded under T_5. The per cent increase in dry fodder yield due to T_5 was 13.8, 10.66, 29.26, 121.82, 32.5, 58.71, 42.28, 64.52 and 42.96 in comparison to T_1, T_2, T_3, T_4, T_6, T_7, T_8, T_9 and T_{10}, respectively. The increase in dry fodder yield could be attributed to the direct impact of different weed control measures, which effectively suppressed weed growth. This reduction in crop-weed competition likely enhanced the crop's ability to accumulate dry matter and absorb nutrients more efficiently.

4. CONCLUSION

The study underscores the vital importance of effective weed management in improving the productivity of fodder sorghum during the Kharif season, particularly in weed-prone and resource-limited areas like Rajasthan. Weed-free conditions maintained up to harvest produced the highest green and dry fodder yield confirming the significant impact of complete weed control. Among the herbicide-based treatments, the sequential application of Atrazine as both pre and post emergent spray proved most effective in reducing weed density and dry matter accumulation. This treatment also delivered the highest green and dry fodder yield among herbicide options, demonstrating its efficacy against a broad spectrum of grassy, sedge, and broad-leaved weeds. The combination of herbicides with different modes of action in Atrazine as both pre and post emergent spray provided extended residual activity, ensuring prolonged weed suppression during critical growth stages. While weed free condition maintained by hand weeding achieved superior control, its labor-intensive and time-consuming nature limits its practical application, especially for large-scale or low-resource farming systems. In contrast, herbicide-based strategies offer scalable, cost-effective, and efficient weed management solutions. Based on these findings, the treatment where Atrazine is applied as both pre and post emergence can be recommended as a reliable and sustainable weed management practice that not only boosts fodder yield but also contributes to narrowing the fodder demand-supply gap, ultimately promoting more resilient and productive agricultural systems in semi-arid regions.

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.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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