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Effect of integrated weed management in *kharif* grain sorghum [*Sorghum bicolor* (L.) Moench]

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Abstract
Field experiment was conducted during *kharif* season 2023 at Agricultural Research Station, Hagari, Karnataka, India to study the effect of integrated weed management in *kharif* grain sorghum. The experiment comprised of eleven treatments allotted in randomized complete block design in which eight treatments with herbicides, two treatments based on hand weeding and inter cultivation and one weedy check, each replicated thrice. The weed free check treatment (T_{10}) as recorded significantly higher growth characteristics like plant height, number of leaves plant^{-1}, leaf area, dry matter production plant^{-1} and yield attributes like length of earhead, number of grains earhead^{-1}, grain weight plant^{-1} and test weight. Whereas, T_{10} was found on par with treatments 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) 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 (T_4). Significantly higher grain and stover yield (3049 and 8880 kg ha^{-1}, respectively) was registered in T_{10}, but it was on par with T_7 (2905 and 8576 kg ha^{-1}, respectively) and T_4 (2809 and 8395 kg ha^{-1}, respectively). Further, significantly lower growth parameter, yield attributes and yield were noticed in weedy check (T_{11}).

Keywords: Integrated weed management, atrazine, metribuzin, yield, Nutrient uptake

Introduction

Sorghum (*Sorghum bicolor* L.) is the fifth most important cereal crop after wheat, rice, maize and barley. It is a self-pollinated C_4 plant with a high photosynthetic efficiency, belongs to the grass family Poaceae and is an important staple food crop in the world. 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. In tropical areas sorghum grain is important as a food as well as livestock feed. The stem and foliage of sorghum are used as a green fodder, hay, silage and pasture. Sorghum grain is used in the preparation of different types of food made from sorghum flour. The grain is boiled to make a porridge or gruel. It is also used in the preparation of biscuits. Beer is also prepared from sorghum grain in many parts of Africa. Sorghum produces the white pearly green grains which are mainly used for food in India for the preparation of roti. It is also an important animal feed (swine, poultry and cattle) used in countries like U.S., Mexico, South America and Australia. Sorghum as a food, feed and bio fuel crop with excellent drought resistance compared to other cereals and is considered as a "Failsafe crop'' (Burke *et al*., 2010) [6].

Sorghum is a unique crop among the major cereals and the staple food and fodder crop of the world's poor and most food-insecure populations, located primarily in the semi-arid tropics. 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) [5]. 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) [4].

Weeds emerge fast and grow rapidly competing with the crop severely for growth resources *viz*., nutrients, moisture, sunlight and space during entire vegetative and early reproductive stages of sorghum. They also transpire lot of valuable conserved moisture and absorb large quantities of nutrients from the soil. Further, wide space provided to the sorghum, allows fast growth of variety of weed species causing a considerable reduction in yield by affecting the growth and yield components. Even though such huge crop produce losses are caused by the weeds, Indian farmers do not pay a quantifiable attention towards weed management as compared to pest, disease, fertilizer and irrigations. This can be observed from the pattern of pesticides usage in India agriculture. Use of herbicides, insecticides and fungicides in India is 10, 76 and 13% respectively, while at global level these figures are 30, 44 and 21%, respectively (Aktar *et al*., 2009) [2]. This may be one reason for low crop productivity in India. Use of pre-emergent and post-emergent herbicides would make the herbicidal weed control more acceptable and economical to farmers, which will not change the existing agronomic practices but will allow for effective management of weeds. 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.

The optimal mineral fertilization is crucial for achieving high-quality crop yields (Sahu *et al*., 2022; Swati *et al*., 2022) [18, 21]. N, P and K are essential plant nutrients, influencing various metabolic processes and overall plant health (Pahade *et al*., 2023) [14]. Nitrogen, in particular, plays a pivotal role in plant metabolism and protein synthesis, with its perishable nature (Stoyanov and Donov, 1996; Verma *et al*., 2023) [20, 22]. Potassium and phosphorus enhance plants resilience against various stressors, further contributing to crop productivity (Sahu *et al*., 2023; Patidar *et al*., 2023) [18, 16]. Our study aimed to evaluate the effect of different treatments on the macroelement content (nitrogen, phosphorus, and potassium) of sorghum plant biomass during field experimentation.

Materials and Methods

During the 2023 *kharif* season, a field experiment was conducted at Agricultural Research Station, Hagari, Ballari. The soil of the experimental area had a neutral pH (7.65), low in EC (0.53 dS m^{-1}) and medium in organic carbon content (5.30 g kg^{-1}). The soil was low in available nitrogen (252.80 kg ha^{-1}), medium in available phosphorus (40.90 kg ha^{-1}) and medium in available potassium (327.10 kg ha^{-1}). 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), metribuzin 70% 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 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. Yield observation on sorghum like grain yield, stover yield and harvest index. Nutrient uptake by plant and weeds by taking a powdered sample of 0.5 gram was pre-digested with 5 ml of concentrated HNO_3 and again digested with a di-acid mixture (HNO_3:$HClO_4$ in the proportion of 10:4). Volume of the digest was made up to 100 ml with distilled water and N, P and K analysis was carried out by using the procedure given (Jackson, 1973) [9]. Total nitrogen, phosphorus and potassium uptake by plant samples was determined by Kjeldahl's method, vanadomolybdophosphoric yellow colour method and flame photometer method.

The composite soil samples from 0-15 cm depth were collected from each treatment at harvest and were air dried in shades, powdered and passed through the 2 mm sieve and analyzed for available N, P and K. The available nitrogen, phosphorus and potassium in soil was estimated by alkaline permanganate oxidation method, Olsen's method and normal ammonium acetate flame photometer method. Soil samples collected from different treatments of experimental plots were used for enumeration of general soil microorganisms *viz*., bacteria, fungi and actinomycetes. Each soil sample was sieved through the 1000 micromesh to remove the bigger particles and debris and was used for enumeration of bacteria, fungi and actinomycetes using Nutrient agar, Martin rose bengal agar (Martin, 1950) [11] and Kuster's agar (Kuster and Williams, 1964) [10] media, respectively by serial dilution pour plate method. The petriplates were incubated at 30 °C for three to six days and population was collected and expressed as CFU g^{-1} of soil (Alef and Nannipieri, 1995) [3]. The dehydrogenase activity in the soil samples was determined by following the procedure as described by (Casida *et al.*, 1964) [7]. 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.

Results and Discussion

Grain and stover yield

Significant variations in sorghum grain and stover yield were noted among different weed management practices detailed in Table 1. The results revealed that significantly higher grain and stover yield was observed in weed free check (T_{10}) and lower grain and stover yield was observed in weedy check (T_{11}). 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 (T_7) has recorded significantly higher grain and stover yield, it was found on par with 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 (T_4) produced higher grain yield. The lower grain and stover yield 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 (T_6). This increase in grain and stover 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. This includes improved dry matter accumulation and distribution in various plant parts, longer earheads, increased grain number per earhead, higher test weight and greater grain weight per earhead. The combined impact of these yield components has led to a significant rise in grain and stover yield of sorghum. These results were similar with findings of Patel *et al*. (2006) [15] in maize crop and Ahlawat *et al*. (2023) [1] in wheat crop with the use of metribuzin herbicide. The lower grain and stover yield in pyroxasulfone applied treatment was due to more crop-weed competition because of less dosage of herbicide and this chemical shows phytotoxicity on sorghum crop. Previous studies by Goodrich *et al.* (2018), Matte *et al*. (2021) and Naveenkumar (2022) [8, 12, 13].

Harvest index

Table 1 provides information on harvest index. Harvest index significantly differ due to various weed management practices. However, numerically higher harvest index was recorded in weed free check (T_{10}) 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 (T_7) and lower harvest index was recorded in weedy check (T_{11}).

Nutrients uptake

Treatments for weed management had a considerable impact on the nitrogen, phosphorus and potassium uptake by sorghum and weeds. Table 2 provides information on nutrient uptake by both sorghum crop and weeds.

Nitrogen, phosphorus and potassium uptake by sorghum crop

Among different treatments, significantly lower nutrient uptake of nitrogen, phosphorus and potassium was recorded from weedy check (T_{11}), whereas significantly higher nutrient uptake by sorghum was observed in weed free check plots (T_{10}). 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 (T_7) was recorded higher significantly higher uptake of nitrogen, phosphorus and potassium the next best treatment is 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). The lower nutrient uptake of nitrogen, phosphorus and potassium was recorded from (T_6) 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. Likewise, significantly higher uptake of nutrients was observed in atrazine and metribuzin treated plot which might be attributed to lower nutrient uptake by weeds due to the control of broad-spectrum weeds by its weed controlling ability when applied at the right doses and at the right time. These results were similar with findings of Patel *et al*. (2006) [15] in maize crop and Ahlawat *et al*. (2023) [1] in wheat crop with the use of metribuzin herbicide.

Nitrogen, phosphorus and potassium uptake by weeds

Significantly higher uptake of nutrient nitrogen, phosphorus and potassium by weeds was observed in weedy check (T_{11}) treatment. There was no nutrient uptake of nitrogen, phosphorus and potassium noticed in weed free check (T_{10}) because of absence of weeds in the treatment due to continuous hand weeding and intercultural operation throughout crop growth period. Among different 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 (T_7) had recorded significantly lower nutrients uptake of nitrogen, phosphorus and potassium. Second best treatment is 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). Significantly higher nutrients uptake of nitrogen, phosphorus and potassium was observed 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 (T_6). Significantly lower nutrient uptake by weeds in atrazine, metribuzin and 2,4-D Na Salt treated plot might be attributed to death of weeds by bleaching effect of chemicals on them due to destruction of chlorophyll in the weed leaves. These findings are in line with the results of the experiments conducted by Rajesh Patil (2020) [17] in sorghum crop, Patel *et al*. (2006) [15] in maize crop and Ahlawat *et al*. (2023) [1] in wheat crop with the use of metribuzin herbicide.

Available nutrients status in the soil after the harvest of crop

Table 3 represents availability of soil nutrients like nitrogen, phosphorus and potassium in each treatment was analysed after the harvest of sorghum. Significantly higher amount of available soil nutrients was recorded in weed free check (T_{10}). The next best treatment was farmers' practice (T_9). Whereas lower amount of these available nutrients in the soil was found in weedy check (T_{11}). 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 recorded significantly higher amount of available soil nutrients (T_7). Second best treatment is 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). Whereas lower amount of available soil nutrients was found 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 (T_6) and pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS (T_3). The notice able disparity in soil nitrogen availability could see from differences in how both the crop and the weeds absorb nitrogen present during the experiment. Similarly, the uptake of available phosphorus by the crop and the weeds, along with the influence of beneficial microorganisms such as naturally occurring phosphate solubilizing bacteria, likely accounts for variations in soil phosphorus availability at the experimental site. Moreover, fluctuations in soil potassium availability might result from varying rates of potassium uptake by crops and weeds, particularly when crucial for crop development. These findings are in close proximity with the results of Vinayaka Shivappa Shidenura (2019) [23] and Rajesh Patil (2020) [17].

Bioassay studies

Total bacterial, fungal and actinomycetes population

Table 4 and 5 represents total microbial population as influenced by different weed management practices. Before sowing in different treatments, total microbial population (bacterial, fungal and actinomycetes population) analysis showed no significant differences, likely due to incomplete treatment imposition. Total microbial population was maximum with weedy check (T_{11}) followed by farmers' practice (T_9) in rhizosphere soil at flowering and harvest as compared to all other treatments. The next best treatment is weed free check (T_{10}) is statistically on par with treatment 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) 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 (T_4). Whereas minimum total microbial population was observed 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 (T_6). The results indicated that, the effect of herbicides on soil microbes is only temporary. The adverse effects of herbicides, if at all were gradually reduced with passage of time and practically there was no adverse effect was observed by these herbicides. But the treatment with application of pyroxasulfone has shown reduction in total microbial population due its toxic effect on bacteria at flowering stage and at harvest. Similar results were also observed by Goodrich *et al.* (2018) [8] and Naveenkumar (2022) [13] in sorghum crop.

Before sowing in different treatments, dehydrogenase activity analysis showed no significant differences which is presented in Table 5. Weedy check (T_{11}) has observed maximum dehydrogenase activity at flowering and harvest as compared to all other treatments. The next treatment is farmers' practice (T_9) was found statistically on par with weed free check (T_{10}), 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) 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 (T_4). The minimum activity was noticed in the plots receiving pyroxasulfone herbicide because of phytotoxic effect. The adverse effects of herbicides, if at all were gradually reduced with passage of time and practically, there was no ill effect of atrazine, metribuzin and 2, 4-D Na Salt on enzyme activity was noticed in rhizosphere soil both at flowering stage and at harvest of sorghum. Similar results were found in experiment conducted by Vinayaka Shivappa Shidenura (2019) [23] and Rajesh Patil (2020) [17].

Economics

Figure 1 represents the economics of *kharif* grain sorghum as influenced by different weed management. Significantly higher net return and benefit cost ratio was observed 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 (T_7). Whereas, weedy check has recorded significantly lower net returns and benefit cost ratio (T_{11}). The higher net returns observed in the T_7 can be attributed to increased grain and stover yields, which are influenced by optimal values of yield and growth-contributing factors. Conversely, lower net returns in the weedy check were due to reduced grain and stover yields resulting from higher weed density and intense crop-weed competition in that treatment.

Table 1: Grain yield, straw yield and harvest index of *kharif* grain sorghum as influenced by different weed management practices

Treatment	**Grain yield (kg ha^{-1})**	**Stover yield (kg ha^{-1})**	**Harvest index (%)**
T_1: Atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	2589	7898	24.7
T_2: Metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	2606	7951	24.7
T_3: Pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	2281	7110	24.3
T_4: 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	2809	8395	25.1
T_5: 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	2516	7473	25.2
T_6: 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	2246	6868	24.6
T_7: 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	2905	8576	25.3
T_8: 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	2380	7362	24.4
T_9: Farmers' practice (One HW at 25 DAS and two IC at 15 & 30 DAS)	2722	8163	25.0
T_{10}: Weed free check	3049	8880	25.5
T_{11}: Weedy check	1536	5673	21.3
S.Em. ±	89	178	0.6
C.D. (P=0.05)	262	526	1.7

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

Table 2: Nitrogen, phosphorus and potassium uptake by *kharif* grain sorghum and weeds as influenced by different weed management practices at harvest

Treatment	**Uptake of nutrients (kg ha^{-1}) by sorghum**			**Uptake of nutrients (kg ha^{-1}) by weeds**		
	Nitrogen (N)	**Phosphorus (P_2O_5)**	**Potassium (K_2O)**	**Nitrogen (N)**	**Phosphorus (P_2O_5)**	**Potassium (K_2O)**
T_1: Atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	143.2	41.1	121.2	16.7	6.4	10.5
T_2: Metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	145.5	41.9	123.9	16.2	5.9	9.8
T_3: Pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	123.5	33.5	103.8	27.1	10.5	15.5
T_4: 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	153.6	47.2	132.4	11.8	4.4	8.6
T_5: 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	136.4	38.7	115.5	18.6	7.5	11.9
T_6: 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	116.3	30.3	101.6	29.9	12.4	18.4
T_7: 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	154.9	48.4	133.8	10.7	3.5	7.9
T_8: 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	134.7	35.4	108.7	23.0	8.7	13.1
T_9: Farmers' practice (One HW at 25 DAS and two IC at 15 & 30 DAS)	149.7	43.6	128.4	12.3	4.7	9.2
T_{10}: Weed free check	158.5	51.2	137.2	0.0	0.0	0.0
T_{11}: Weedy check	72.1	25.4	68.1	58.0	16.9	39.1
S.Em. ±	2.0	2.0	1.8	0.6	0.4	0.5
C.D. (P=0.05)	5.9	6.0	5.4	1.6	1.2	1.3

Table 3: Effect of different weed management practices on available NPK (kg ha^{-1}) content in soil after harvest of *kharif* grain sorghum

Treatment	Available nutrients (kg ha^{-1})		
	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
T_1: Atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	161.5	45.1	195.3
T_2: Metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	164.8	46.7	196.8
T_3: Pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	147.7	39.4	172.9
T_4: 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	174.6	51.4	205.3
T_5: 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	155.5	43.8	187.4
T_6: 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	145.1	37.9	167.1
T_7: 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	176.0	52.1	207.3
T_8: 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	151.4	42.2	182.7
T_9: Farmers' practice (One HW at 25 DAS and two IC at 15 & 30 DAS)	168.5	48.2	201.6
T_{10}: Weed free check	181.8	54.3	210.1
T_{11}: Weedy check	115.6	33.1	137.7
S.Em. ±	2.6	1.6	2.0
C.D. (P=0.05)	7.6	4.6	5.8

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

Table 4: The total bacterial and fungal population in soil at different growth stages of *kharif* grain sorghum as influenced by different weed management practices

Treatment	Total bacterial population (× 10^6 cfu g^{-1})			Total fungal population (× 10^4 cfu g^{-1})		
	Before sowing	At 60 DAS	At harvest	Before sowing	At 60 DAS	At harvest
T_1: Atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	17.6	48.6	23.1	4.2	11.4	7.2
T_2: Metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	16.6	49.4	24.6	4.6	11.8	7.4
T_3: Pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	16.9	39.4	19.3	4.7	10.1	6.5
T_4: 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	17.8	51.9	26.7	4.4	12.5	7.7
T_5: 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	16.9	47.8	22.7	4.7	10.9	6.9
T_6: 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	17.9	38.9	18.9	4.9	9.9	6.4
T_7: 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	18.2	52.4	27.4	4.4	13.1	8.1
T_8: 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	17.7	40.6	20.4	4.8	10.6	6.8
T_9: Farmers' practice (One HW at 25 DAS and two IC at 15 & 30 DAS)	18.1	57.7	31.1	4.5	15.7	10.5
T_{10}: Weed free check	17.5	56.7	30.7	5.0	15.3	10.0
T_{11}: Weedy check	16.8	63.0	33.5	4.9	16.9	13.1
S.Em. ±	0.6	2.4	1.5	0.3	1.2	0.9
C.D. (P=0.05)	NS	7.2	4.4	NS	3.4	2.5

Note: WP: Wettable powder, PE: Pre-emergence, *fb*: Followed by, IC: Inter cultivation, DAS: Days after sowing, WG: Water-dispersible granules, PoE: Post-emergence, HW: Hand Weeding, cfu: Colony forming unit, NS: Non-significant

Table 5: The total actinomycetes population and dehydrogenase activity in soil at different growth stages of *kharif* grain sorghum as influenced by different weed management practices

Treatment	Total actinomycetes population (× 10^3 cfu g^{-1})			Dehydrogenase activity (µg TPF g^{-1} soil day^{-1})		
	Before sowing	At 60 DAS	At harvest	Before sowing	At 60 DAS	At harvest
T_1: Atrazine 50% WP @ 500 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	3.7	20.9	12.5	6.8	21.6	14.6
T_2: Metribuzin 70% WP @ 100 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	3.8	21.3	12.7	7.4	21.9	14.9
T_3: Pyroxasulfone 85% w/w WG @ 65 g *a.i.* ha^{-1} as PE *fb* IC at 25 DAS	3.9	20.0	11.2	7.1	18.5	13.5
T_4: 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	3.8	22.0	13.2	6.9	23.0	15.6
T_5: 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	4.1	20.7	12.1	6.7	19.8	14.3
T_6: 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	3.9	19.6	11.0	7.3	18.1	13.2
T_7: 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	3.6	22.5	13.7	7.1	23.6	16.0
T_8: 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	3.7	20.3	11.5	6.3	19.0	13.6
T_9: Farmers' practice (One HW at 25 DAS and two IC at 15 & 30 DAS)	4.0	24.7	14.8	7.2	25.8	17.7
T_{10}: Weed free check	3.8	24.3	14.5	6.5	25.3	17.4
T_{11}: Weedy check	4.1	26.0	16.5	7.3	28.1	19.4
S.Em. ±	0.2	1.0	0.6	0.4	1.1	0.8
C.D. (P=0.05)	NS	2.9	1.7	NS	3.2	2.4

Note: WP: Wettable powder, PE: Pre-emergence, *fb*: Followed by, IC: Inter cultivation, DAS: Days after sowing, WG: Water-dispersible granules, PoE: Post-emergence, HW: Hand Weeding, TPF: Triphenylformazan, NS: Non-significant

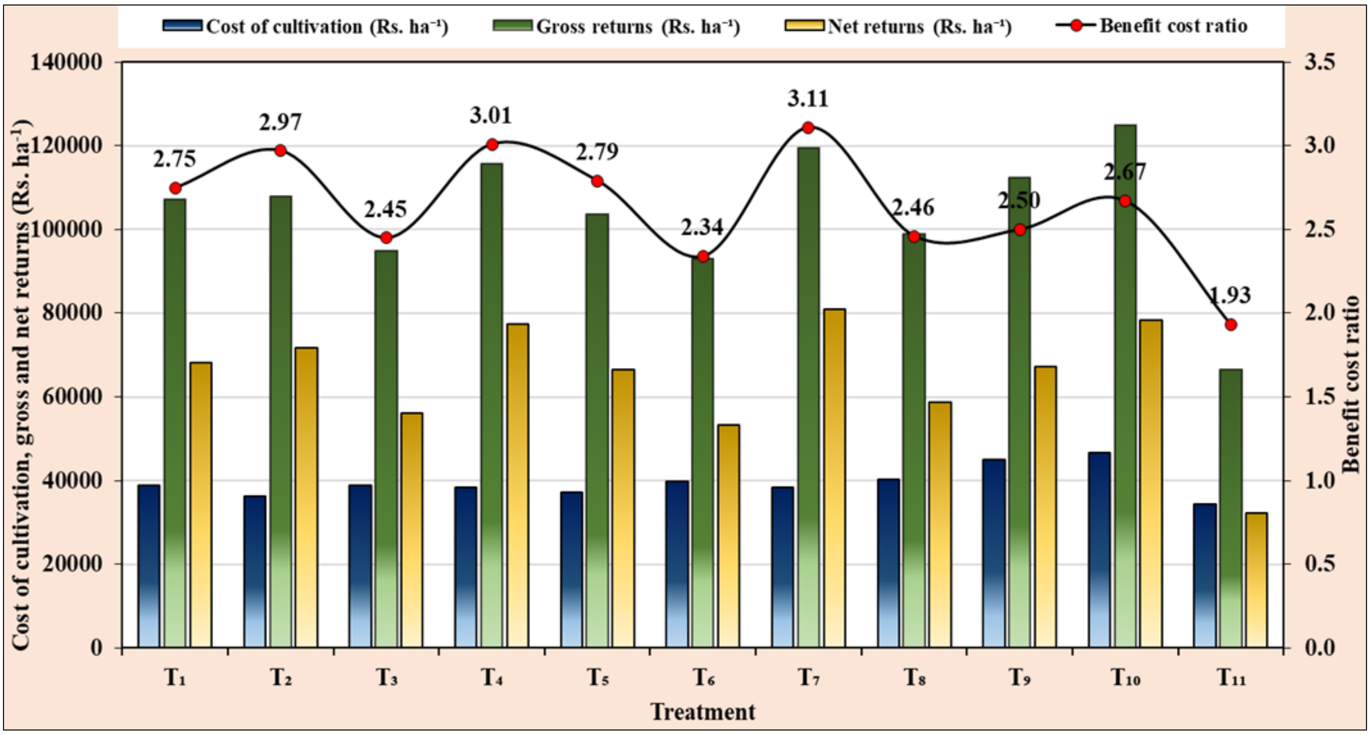

Fig 1: Economics of *kharif* grain sorghum as influenced by different weed management practices

Conclusion

The study revealed significant variations in NPK uptake by crops and weeds and available nutrients in soil under various weed management treatments. Among herbicide treatments highest nutrient uptake by sorghum and available nutrients in soil was recorded 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 (T_7). Similarly, highest total microbial population and dehydrogenase activity was noticed in T_7 treatment.

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