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Research Paper

Integrated weed management in rainy season sorghum (*Sorghum bicolor*)

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ABSTRACT

A field experiment was carried out during the rainy season of 2011 and 2012 in *Vertisols* at Dharwad, Karnataka, to develop integrated weed management for hybrid sorghum [*Sorghum bicolor* (L.) Moench] with pre-emergence application of atrazine @ 0.5 kg/ha, post-emergence application of atrazine @ 0.75 kg/ha, 2, 4-D @ 0.5 kg/ha, metsulfuron methyl @ 4 g and 6 g/ha, intercultivation and hand-weeding. The maximum average grain yield (4.42 t/ha) was recorded with pre-emergence application of atrazine @ 0.5 kg/ha, followed by post-emergence application of 2, 4-D @ 0.75 kg/ha at 20 days after sowing and interculturing at 30 days after sowing, which was at par with weed free treatment and increased the yield by 39.8% over weedy check and 6.5% over farmer's practice. The higher grain yield may be owing to significantly lower weed dry weight, higher weed-control efficiency and higher nutrient uptake by sorghum which reflected in higher values of grain weight/ear, ear length and 1,000-grain weight. In weedy check, weeds removed 20.5 kg N/ha, 14.9 kg P/ha and 22.3 kg K/ha, being higher than rest of the weed-management practices. Maximum net returns (₹29,530/ha) and benefit: cost ratio (2.43) were realized with atrazine @ 0.5 kg/ha (PE), followed by 2, 4-D @ 0.75 kg/ha (PoE) at 20 days after sowing and intercultivation at 30 days after sowing.

Key words : Crop protection, Grain yield, Nutrient uptake, Sorghum, Weed control

Sorghum is one of the important cereal crops globally after wheat, maize, rice and barley. It is an unique crop among the major cereals and the staple food and fodder crop of the world's poor and most food insecure populations in the semi-arid tropics. In India, the area and production of rainy (*kharif*) sorghum during 2010–11 was 7.06 million ha and 6.74 million tones, respectively with productivity of 1,047 kg/ha. In Karnataka, it is cultivated over an area of 1.37 million ha with a production and productivity of 1.41 million tonnes and 1,029 kg/ha respectively GOI, (2012). Productivity of the rainy-season sorghum is declining every year due to use of local varieties/hybrids, imbalanced application of fertilizers including micronutrients, non-adoption of weed-management practices particularly in assured rainfall areas. Mishra (1997) reported 15–40% loss in grain yield due to weed competition in sorghum. Weed infestations in early growing season will reduce yields significantly. Wet soil conditions during the rainy season in medium to deep black soils do not permit either mechanical weeding or hand-weeding to create weed-free conditions. Hence under such a situation, use of herbicides is the best option to reduce the weed menace during early stages of growth. However, neither herbicides nor mechanical cultivations are adequate for consistent and acceptable weed control. The integration of herbicides with some cultural operations or use of pre-emergence and post-emergence herbicides in combination with mechanical methods can prove to be more successful (Ishya *et al*., 2007). Thus integrated weed management is gaining importance in management of weeds for preventing losses and higher input-use efficiency. Therefore, the present experiment was conducted to find out the effect of integrated weed management on productivity, weed dynamics, nutrients removal and economics of rainy-season sorghum in vertisols.

MATERIALS AND METHODS

The field experiment was carried out during the rainy season of 2011 and 2012 at Dharwad (15° 26'N, 75° 07'E and 678 m above mean sea-level), Karnataka under rainfed conditions to evaluate the effect of herbicides and their mixture on weed control and rainy-season sorghum productivity. The experimental site has deep black soil with pH (6.5), organic C (0.54%), available N (192 kg/ha), P (15.9 kg/ha) and K (390 kg/ha). Ten treatments comprised atrazine @ 0.5 kg/ha pre-emergence (PE) followed

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by atrazine @ 0.5 kg/ha post-emergence (PoE), atrazine @ 0.5 kg/ha (PE) followed by atrazine @ 0.75 kg/ha (PoE), atrazine @ 0.5 kg/ha (PE) followed by 2,4-D @ 0.5 kg/ha (PoE), atrazine @ 0.5 kg/ha (PE) followed by 2,4-D @ 0.75 kg/ha (PoE), atrazine @ 0.5 kg/ha (PE) followed by metsulfuron methyl @ 4 g/ha (PoE), atrazine @ 0.5 kg/ha (PE) followed by metsulfuron methyl @ 6 g/ha (PoE), recommended package of practice(RPP), weed-free check and weedy check were evaluated in randomized block design with 3 replications. Post-emergence herbicide was applied at 20 days after sowing, intercultivation was done at 30 days after sowing and hand-weeding was done at 45 days after sowing as per different treatments. Hybrid sorghum 'CSH 14' was sown at 45 cm × 15 cm spacing on 14 June 2011 and 9 July 2012. The delayed sowing during 2012 was due to late onset of monsoon. The gross plot size was 5.5 m × 4.5 m and crop was fertilized with 100 kg N, 75 kg P_2O_5 and 25 kg K_2O/ha through urea, diammonium phosphate and murate of potash respectively. At sowing 50% N along with full dose of P and K were applied. Phorate granules @ 12 kg/ha were mixed with fertilizers and applied for the control of shoot fly. The remaining 50% N was top-dressed at 30 days after sowing. There was no much variation in weather during the cropping period like relative humidity and maximum and minimum temperature in both the years. During the period of study, the mean relative humidity varied from 92.8 to 94.9% during 2011 and 90.5 to 93.9% during 2012. Similarly, minimum temperature (19.8 to 20.8°C during 2011 and 18.6 to 20.8°C during 2012) and maximum temperature (26.3 to 29.5°C during 2011 and 26.7 to 29.9°C during 2012) did not vary much during the cropping period. Total rainfall (475.0 mm) received in 2011 during the cropping period was higher than 2012 (398.5 mm), which could be reflected in higher yield of sorghum. The similar trend in yield due to different treatments was observed during both the years. Weed population 60 days after sowing and at harvest, and weed dry matter at harvest were recorded from pre-marked quadrats of 1 m^2 area. The weed count data were subjected to square root transformation ($\sqrt{x+1}$) to normalize the distribution. Weed-control efficiency and weed index were worked out to assess the efficiency of different weed-control treatments. The phytotoxicity on crop due to herbicides was recorded using 0–10 scale. The data on growth parameters, dry-matter production and its distribution were recorded from 5 randomly selected plants at 60 days after sowing and at harvest. The crop was harvested on 20 October 2011 and 23 November 2012. The concentrations of N, P, K were analyzed in crop and weeds and their uptake was calculated. The economics were calculated based on prevailing market prices of inputs and out puts.

RESULTS AND DISCUSSION

Weed dynamics

The major weed flora in the field comprised 28.2% of grassy weeds like *Cynadon doctylon, Digitaria sanguinalis, Dinebra retroflexa, Echinochloa colona*; 12.5% of sedges like *Cyperus rotundus*; and 58.9% of broad-leaf weeds like *Ageratum conyzoides, Amaranthus viridis, Commelina bengalensis and Phyllanthus niruri.* In both the years, density of broad-leaf weeds was more than of the grassy weeds and sedges.

All the applied herbicides did not control grassy weeds, sedges and provided effective control over broad-leaf weeds at 60 days after sowing. This may be due to their differential selectivity towards broadleaf weeds Enrique *et al*. (2005). Among the weed-management practices, atrazine @ 0.5 kg/ha (PE) followed by 2, 4-D @ 0.75 kg/ha (PoE) at 20 days after sowing and intercultivation at 30 days after sowing recorded significantly higher reduction of broad-leaf weeds to an extent of 94.9% over weedy check and 87.2% over farmers practice (Table 1), indicating its superiority to the other treatments.

Weed dry weight reflects the growth potential of the weeds and is a better indicator of its competitive ability with the crop plants. Weed dry weight was significantly reduced under all herbicidal treatments compared to weedy check and farmers practice. Application of atrazine @ 0.5 kg/ha (PE) followed by 2, 4-D @ 0.75 kg/ha (PoE) at 20 days after sowing and intercultivation at 30 days after sowing recorded significantly lower weed dry weight, higher weed control efficiency and lower weed index than the other treatments owing to effective control of complex weed flora. Similar observations were reported in sorghum by Sharma (2000). Higher weed dry weight, weed index and lower weed-control efficiency were recorded in herbicidal treatments where metsulfuron methyl @ 4 g and 6 g/ha were used as post-emergence herbicides due to higher total weed density (Patrick *et al*., 2009). Un-weeded check recorded the highest weed growth and weed biomass (Table 1).

Nutrient removal by weeds and crop

The N, P, and K removal by weeds was significantly influenced by various weed-management practices (Table 1). Nutrient removal by weeds was lowest in weed-free plot and the highest removal was recorded in weedy check plot. Application of atrazine @ 0.5 kg/ha (PE) followed by 2, 4-D @ 0.75 kg/ha (PoE) at 20 days after sowing and intercultivation at 30 days after sowing recorded lower nutrient removal by the weeds compared to other herbicides treatments. Therefore, it is well augmented that weeds should be eradicated at an early stage of crop growth. Any delay in weed control may result in robbing

Table 1. Effect of weed-management practices on weed growth and nutrient removal in sorghum (pooled data of 2 years)

Treatment	Total weed population at 60 DAS (no/m^2)			Weed dry weight at 60 DAS (g/m^2)	Weed-control efficiency at 60 DAS (%)	Weed index at harvest (%)	Nutrient removal by weeds (kg/ha) at harvest		
	Grassy weeds	Sedges	Broad leaf weeds				N	P	K
Atrazine @ 0.5 kg/ha (PE) fb atrazine @ 0.5 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	2.34(5.00)	1.22(1.00)	1.68(2.33)	2.02(3.60)	83.1	8.62	12.26	5.40	11.19
Atrazine @ 0.5 kg/ha (PE) fb atrazine @ 0.75 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	2.31(4.83)	1.05(0.67)	1.56(2.00)	1.96(3.33)	84.4	7.47	10.94	5.99	10.19
Atrazine @ 0.5 kg/ha (PE) fb 2,4-D @ 0.5 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	2.41(5.33)	0.88(0.33)	1.56(2.00)	1.88(3.07)	84.8	7.13	10.49	4.55	7.22
Atrazine @ 0.5 kg/ha (PE) fb 2,4-D @ 0.75 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	2.73(7.00)	0.88(0.33)	1.46(1.67)	1.87(3.00)	85.9	2.79	6.40	2.97	5.39
Atrazine @ 0.5 kg/ha (PE) fb metsulfuron methyl @ 4 g/ha (PoE) at 20 DAS fb IC at 30 DAS	2.41(5.33)	1.58(2.00)	1.56(2.00)	2.21(4.40)	79.4	20.49	9.23	4.91	11.21
Atrazine @ 0.5 kg/ha (PE) fb metsulfuron methyl @ 6 g/ha (PoE) at 20 DAS fb IC at 30 DAS	2.48(5.67)	1.46(1.67)	1.56(2.00)	2.18(4.27)	80.0	25.03	10.63	5.99	11.55
Recommended package of practice (Atrazine @ 0.5 kg/ha (PE) fb 2 IC at 20 and 30 DAS fb 1 HW at 45 DAS)	2.41(5.33)	1.05(0.67)	1.68(2.33)	1.96(3.33)	84.4	4.86	11.28	5.54	9.36
Farmers practice (Two IC at 20 and 30 DAS + 1 HW at 45 DAS)	2.48(5.67)	1.17(1.00)	3.67(13.00)	2.27(4.70)	78.0	8.68	10.51	5.88	10.33
Weed free	1.22(1.00)	0.71(0.0)	1.22(1.00)	1.14(0.80)	96.3	0.00	5.00	2.07	4.05
Weedy check	4.06(16.00)	2.73(7.00)	5.55(33.0)	4.67(21.33)	-	30.52	20.52	14.93	22.26
SEm±	0.13	0.15	0.14	0.11		1.38	1.21	0.75	1.38
CD(P=0.05)	0.40	0.44	0.42	0.45	—	4.09	3.60	2.21	4.11

Figures in the parentheses are the original values and outside ones are square root ($\sqrt{x+1}$) transformed values
PE, pre-emergence; PoE, post-emergence; fb, followed by; IC, intercultivation; HW, hand-weeding; DAS, days after sowing

off nutrients by weeds and depriving the crop of its share (Hanwen *et al*., 2010).

All the weed-control practices except those involving metsulfuron methyl resulted in significantly higher uptake of plant nutrients over the weedy check. Weed-free treatment and atrazine @ 0.5 kg/ha (PE) followed by 2, 4-D @ 0.75 kg/ha (PoE) at 20 days after sowing and intercultivation at 30 days after sowing recorded 75.6 and 66.3% increase in N uptake, 86.4 and 83.3% increase in P uptake and 42.3 and 38.5% increase in K uptake over weedy check (Table 3). Favourable crop growth conditions as well as lower crop–weed competition which resulted in higher grain and dry fodder yield contributed to this higher nutrient uptake by crop. While the integrated weed management having metsulfuron methyl @ 4 g and 6 g/ha registered lower NPK uptake by crop which may be attributed to lower grain and dry fodder yield due to their phytotoxicity on crop. Ishya *et al*. (2007) reported the phytotoxicity of metsulfuron methyl on sorghum.

Performance of sorghum

All the integrated weed-management practices except those with metsulfuron methyl and weed free check recorded higher values of growth and yield attributes compared to weedy check and farmers practice. Among herbicidal treatments, atrazine @ 0.5 kg/ha (PE) followed by 2,4-D @ 0.75 kg/ha (PoE) at 20 days after sowing and intercultivation at 30 days after sowing and weed free check registered respectively, 25.6 and 25.9% increase in grain weight/ear, 32.4 and 35.2% increase in ear length and 9.9 and 13.7% increase in 1,000-grain weight compared to weedy check. Weed-free conditions increased the availability of nutrients, space and light to sorghum crop due to absence of crop-weed competition, which resulted in increased values of yield attributes (Table 2). Integrated weed management involving metsulfuron methyl @ 4 g and 6 g/ha showed their phytotoxicity on sorghum till 21 days after spraying and the crop was recovered during later growth period. But the crop growth was reduced which reflected in lower values of growth and yield attributes. The reduction in growth and yield attributes due phytotoxic effect of metsulfuron methyl on sorghum was reported by Shane Hennigh *et al*. (2010).

Though the grain yield during 2011 was higher than 2012 owing to higher rainfall, a similar trend in grain yield due to different treatments was observed during both the years. The complex weed flora comprising grasses, sedges and broad-leaf weeds showed reduction of 43.9% and 39.8% in grain and 37.3 and 29.0% in dry fodder yield in weedy check compared to weed-free and atrazine @ 0.5 kg/ha (PE) followed by 2, 4-D @ 0.75 kg/ha (PoE) at 20 days after sowing and intercultivation at 30 days after sow-

Table 2. Effect of weed-management practices on growth and yield of sorghum (pooled data of 2 years)

Treatment	Plant height (cm) at harvest	Leaf area index at harvest	Grain weight/ ear(g)	Ear length (cm)	1,000-grain weight(g)	Phytotoxicity ratings (0-10 scale) at 21 DAPoE
Atrazine @ 0.5 kg/ha (PE) fb atrazine @ 0.5 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	154	3.87	29.32	27.4	31.04	0.0
Atrazine @ 0.5 kg/ha (PE) fb atrazine @ 0.75 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	156	3.74	29.29	27.9	30.52	0.0
Atrazine @ 0.5 kg/ha (PE) fb 2,4-D @ 0.5 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	155	3.94	30.22	28.1	30.02	0.0
Atrazine @ 0.5 kg/ha (PE) fb 2,4-D @ 0.75 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	156	3.97	30.36	28.2	30.38	0.0
Atrazine @ 0.5 kg/ha (PE) fb metsulfuron methyl @ 4 g/ha (PoE) at 20 DAS fb IC at 30 DAS	141	3.30	24.15	26.6	29.06	2.0
Atrazine @ 0.5 kg/ha (PE) fb metsulfuron methyl @ 6 g/ha (PoE) at 20 DAS fb IC at 30 DAS	138	2.51	24.60	26.2	28.74	4.0
Recommended package of practice (Atrazine @ 0.5 kg/ha (PE) fb 2 IC at 20 and 30 DAS fb 1 HW at 45 DAS)	154	3.72	30.29	27.5	30.23	0.0
Farmers practice (Two IC at 20 and 30 DAS+1 HW at 45 DAS)	150	3.72	29.41	27.1	30.04	0.0
Weed-free	159	4.18	30.44	28.8	31.43	0.0
Weedy check	111	1.62	24.16	21.3	27.64	0.0
SEm±	3	0.19	1.49	0.83	0.73	-
CD (P=0.05)	9	0.57	4.43	2.46	2.17	-

PE, pre-emergence; PoE, post-emergence; fb, followed by; IC, intercultivation; HW, hand-weeding; DAS, days after sowing; DAPoE, days after post-emergence spray

Table 3. Effect of weed-management practices on nutrient uptake, grain yield and economics of sorghum (pooled data of 2 years)

Treatment	Nutrient uptake (kg/ha)			Grain yield (t/ha)		Dry fodder yield (t/ha)	Cost of cultivation (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio
	N	P	K	2011	2012				
Atrazine @ 0.5 kg/ha (PE) fb atrazine @ 0.5 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	95.4	17.9	136.9	4.39	3.91	9.45	20.70	26.77	2.29
Atrazine @ 0.5 kg/ha (PE) fb atrazine @ 0.75 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	97.1	20.6	134.6	4.41	4.02	9.83	20.86	27.53	2.32
Atrazine @ 0.5 kg/ha (PE) fb 2,4-D @ 0.5 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	102.2	20.8	139.2	4.53	3.91	9.83	20.54	27.40	2.33
Atrazine @ 0.5 kg/ha (PE) fb 2,4-D @ 0.75 kg/ha (PoE) at 20 DAS fb IC at 30 DAS	109.1	24.2	142.5	4.68	4.16	9.83	20.61	29.53	2.43
Atrazine @ 0.5 kg/ha (PE) fb metsulfuron methyl @ 4 g/ha (PoE) at 20 DAS fb IC at 30 DAS	75.1	13.7	106.4	3.76	3.72	7.88	20.41	21.45	2.05
Atrazine @ 0.5 kg/ha (PE) fb metsulfuron methyl @ 6 g/ha (PoE) at 20 DAS fb IC at 30 DAS	71.6	11.7	100.8	3.54	3.28	6.95	20.42	19.05	1.97
Recommended package of practice (Atrazine @ 0.5 kg/ha (PE) fb 2 IC at 20 and 30 DAS fb 1 HW at 45 DAS)	104.4	17.7	137.9	4.43	4.23	9.32	21.68	26.91	2.24
Farmers practice (Two IC at 20 and 30 DAS+1 HW at 45 DAS)	92.2	16.6	131.3	4.21	4.08	9.45	21.16	26.31	2.24
Weed-free	115.0	24.6	146.4	4.64	4.02	10.46	29.96	25.15	1.93
Weedy check	65.6	13.2	102.9	3.31	3.01	7.62	19.06	18.54	1.97
SEm±	1.9	0.8	5.3	0.14	0.11	0.38		0.38	0.08
CD (P=0.05)	4.01	2.3	15.8	0.39	0.31	1.13	–	1.13	0.23

PE, pre-emergence; PoE, post-emergence; fb, followed by; IC, inter-cultivation; HW, hand-weeding; DAS, days after sowing
Cost of inputs (₹/kg): Sorghum seeds, 48, Urea, 5.80; DAP, 9.20; MOP, 5.30; Atrazine, 320/kg; 2, 4-D, 250; Metsulfuron methyl, 1,400; cost of operations; Labour, ₹100/day; IC, ₹1,200/ha; HW, ₹2,500/ha; Spraying, ₹400/ha; Price of outputs, Sorghum grain, ₹1,000/q and dry fodder, ₹600/t

ing during both years due to control of total weed flora. Better performance of theses treatments in terms of yield could be owing to higher plant height, leaf-area index, grain weight/ear, ear length and 1,000-grain weight due to higher uptake of NPK by crop and better control of complex weed flora tilting the crop-weed competition in favour of crop (Enrique *et al*., 2005). In both the years, atrazine @ 0.5 kg/ha (PE) followed by metsulfuron methyl @ 4 g and 6 g/ha (PoE) at 20 days after sowing and intercultivation at 30 days after sowing failed to increase the grain and dry fodder yield significantly over weedy check due to its phytoxicity on crop which reflected in reduced crop growth and lower nutrient uptake by crop. David *et al*. (2004) reported the similar results in sorghum.

Economics

Economic analysis of data showed that the integrated weed management practices differed with cost involved in production, net returns and benefit: cost ratio. All the integrated weed-management practices showed higher monetary returns over weedy check (Table 3). Among them, atrazine @ 0.5 kg/ha (PE) followed by 2, 4-D @ 0.75 kg/ha (PoE) at 20 days after sowing and intercultivation at 30 days after sowing gave the maximum net returns and benefit: cost ratio owing to excellent weed control of complex weed flora without any adverse effect on crop growth, higher grain and dry fodder yield. The integrated weed-management practices with metsulfuron methyl @ 4 g and 6 g/ha recorded lower net returns and benefit: cost ratio compared to other practices which may be attributed to lower grain and dry fodder yields due to their phytotoxicity on the sorghum crop. Weed-free treatment registered lower monetary returns due to high cost involved in repeated weedings to keep crop weed-free despite having highest grain and dry fodder yield, as also reported by Rao *et al*. (2007).

It may be concluded that application of atrazine @ 0.5 kg/ha (PE) followed by 2, 4-D @ 0.75 kg/ha (PoE) at 20 days after sowing and intercultivation at 30 days after sowing appeared to be the best integrated weed-management practice in reducing weed growth, producing maximum yield and net returns in the rainy-season sorghum.

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