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Response of grain sorghum (*Sorghum bicolor*) cultivars to weed competition in semi-arid tropical India

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ABSTRACT

The performance of eleven grain sorghum [*Sorghum bicolor* (L.) Moench] cultivars on weed competition was evaluated in the semi-arid tropics of India during rainy seasons of 2009 and 2010 at Hyderabad. The experiment consisted of the three weeding levels (unweeded check, atrazine 0.50 kg/ha + hoeing once at 30 days after sowing-DAS, and atrazine + hoeing twice at 30 and 45 DAS) as the main plot treatments and eleven grain sorghum cultivars (CSH 16, CSH 23, CSH 14, SPH 1596, SPH 1606, SPH 1616, CSV 15, CSV 17, CSV 20, CSV 23, SPV 462) as the sub plots, was replicated thrice in a split-plot design. The cultivar competitiveness was associated with its ability to intercept solar radiation. Sorghum leaf area index (LAI) was negatively correlated (r = –0.82**) with a light transmission ratio (LTR) and weed dry weight at harvest (r = –0.81**). The yield reduction due to weed competition among cultivars varied from 21 to 53%. Grain yield was significantly and positively correlated with initial fresh shoot weight (r = 0.61*), LAI (r= 0.84**), panicle number (r = 0.68**), and significantly negatively correlated with weed biomass (r = –0.62*) and LTR (r = –0.77**). Sorghum hybrids CSH 16 resulted in better weed suppression, whereas CSH 14, SPH 1616 and SPH 1606 tolerated higher weed pressure. CSH 16 (unweeded and weeded once), and SPH 1596 (weeded twice) were the most profitable. Results showed that growing sorghum hybrid CSH 16 and controlling weeds with atrazine at 0.50 kg/ha as pre-emergence followed by 1 hoe weeding at 30 DAS would lead to higher yield and profits.

Key words: Economics, Grain sorghum cultivars, Weed competition, Weed dry weight, Weeding levels

Sorghum [*Sorghum bicolor* (L.) Moench], the fifth most important cereal crop on the globe is traditionally grown for food, animal feed and fodder, building material and fuel in subtropical and semi-arid regions of Asia, Africa and United States. Because of its drought adaptation capability, sorghum is a preferred crop in tropical, warmer and semi-arid regions of the world with high temperature and water stress. Weeds are a major deterrent in increasing the grain sorghum productivity and quality (Geier *et al.* 2009). Grain sorghum seedlings are comparatively small and grow slowly for the first 20-25 days (Rizzardi *et al.* 2004) and consequently do not compete well with most weeds in the early stage of crop growth. Yield loss in grain sorghum due to weeds ranges from 15 to 97% depending on crop cultivars, the nature and intensity of weeds, spacing, duration of weed infestation and environmental conditions (Mishra 1997, Tamado *et al.* 2002). Currently, hand weeding and mechanical cultivation are the most common methods to suppress weeds in grain sorghum in semi-arid tropical regions. Scarcity of labour for hand weeding, and high cost are the major limitations of hand weeding. Atrazine is the most commonly used herbicide to control weeds in grain sorghum. However, it has a low effectiveness on grasses (Dan *et al.* 2011a). The increasing herbicide cost, non-availability to small-holder farmers at the time of need, lack of knowledge and skill of correct use of herbicides are the major concerns of farmers to reduce reliance on herbicide usage.

Variation in competitive ability against weeds among sorghum cultivars offers opportunities to select and breed for competitive cultivars that can be adopted by the farmers as a part of integrated weed management programme. Integration of reduced rates of herbicide application with competitive cultivars would provide a safe and environmentally benign tool for integrated weed management. The objective of the present study was to assess the performance of grain sorghum cultivars under different weed management practices.

MATERIALS AND METHODS

Field experiments were conducted at the Directorate of Sorghum Research, Hyderabad India (17° 31’ N, 78° 39’ E, and 545 m above mean sea level) heduring the rainy seasons of 2009 and 2010. The climate of the area is semi-arid and tropical, with an average annual rainfall of 857 mm (75-

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80% of which is received during June-September), minimum temperature of 8-10°C in December, and maximum temperature of 40-42°C in May. The total rainfall received during cropping season (June-October) was 601.2 and 947.5 mm in 2009 and 2010, respectively. The soil was an Alfisol, Udic Rhodustalf, sandy loam (66% sand, 13% silt and 21% clay), with 7.42 pH, 0.18 dS/m electrical conductivity, 0.39% organic carbon, 1.63 g/cc bulk density, 7.34% available soil moisture; low in available N (163 kg/ha), medium in available phosphorus (29 kg P_2O_5/ha) and high in potassium (360 kg K_2O/ha) content. The experiment was conducted in a split-plot design with randomized complete blocks replicated three times. Main plot treatments were unweeded check, atrazine 0.50 kg/ha + hoeing once at 30 DAS, and atrazine + hoeing twice at 30 and 45 DAS. Eleven grain sorghum cultivars including six hybrids and 5 inbreds (open pollinated varieties) (Table 1) were the subplot treatments. Plots were seeded manually on 8 July in 2009 and 17 June in 2010 in rows 45 cm apart at an intra-row spacing of 15 cm and was later thinned to one plant per stand at 15 DAS. Atrazine was applied one day after sowing with 500 l/ha of water with the help of knapsack sprayer, fitted with flat-fan nozzle. Fertilizer (80 kg N, 40 kg P_2O_5 and 40 kg K_2O/ha) was applied as recommended for grain sorghum in the area. All the phosphorus as single super phosphate and potassium as muriate of potash were applied as basal on the day of planting. Nitrogen as urea was applied in 2 splits, 50% at sowing and remaining at 35 DAS. Two irrigations were given during reproductive stage in 2009 due to less and erratic rainfall, whereas no irrigation was required in 2010.

Weed count, for estimating weed density, and total weed dry weight was recorded at crop maturity with the help of a quadrate (0.50 m × 0.50 m) placed randomly at four spots in each plot in each year. Weeds within each quadrat were uprooted, separated species wise and counted. After removing the roots, weeds were washed with tap water, sun dried, hot-air oven-dried at 70°C for 48 hr, and then weighed. Five randomly selected plants from each plot were evaluated for shoot length, root length, fresh shoot weight, dry shoot weight and leaf area index. Leaf area was measured at 15, 30 and 60 DAS by removing all the leaves from each of five randomly selected plants from each plot and passing them individually through a stationary leaf area meter [(Model: LI-COR 3100 (Li-COR Inc., P O Box 4425, Lincoln, NE 68504)]. The light transmission ratio (LTR) was recorded by using a digital Lux Meter. The light intensity above the crop and weed canopy was recorded in between 11:30 am to 12:30 PM and the light transmission ratio was calculated by the formula given by the Yoshida *et al.* (1972).

$$LTR = \frac{li}{l0} \times 100$$

where, LTR, Light transmission ratio (%); li, light intensity received above the weed canopy; l0, light intensity received above the crop canopy.

The economic requirements for all the treatments were measured for the growing period of the crops during 2010 (completion of the experiment). Gross returns was calculated on the basis of minimum support price declared by the Government of India for rainy season grain sorghum (₹ 9 500/Mg). Net income was calculated as the difference between gross income and total cost. Benefit: cost ratio was worked out by dividing gross returns with a total cost of cultivation. Data were analyzed with Statistix 8.1 for analysis of variance (ANOVA). Treatments were compared by computing the "F-test". The significant differences between treatments were compared pare wise by critical difference at the 5% level of probability.

RESULTS AND DISCUSSION

Weed species composition and growth

To assess the weed infestation, weed density (number/m^2) was recorded at crop maturity in unweeded control. The

Table 1 Characteristics of the grain sorghum cultivars used for the trials during 2009 and 2010

Cultivar	Pedigree	Year of release and place	Plant height (cm)	Days to 50% flowering	Maturity duration (days)
Hybrid					
CSH 16	27 A × C 43	1997, DSR, Hyderabad	190-210 (medium)	68-72	110-115
CSH 23	MS 7A × RS 627	2005, DSR, Hyderabad	180-200 (medium)	64-66	105-110
CSH 14	AKMS 14A × AKR 150	1992, PDKV, Akola	180-200 (medium)	65-67	103-105
SPH 1596	NA	Mahodaya Hybrid, Hyderabad	170-180 (medium)	68-70	110-115
SPH 1606	NA	Krishdhan Seeds, Hyderabad	180-200 (medium)	67-70	110-115
SPH 1616	NA	Emergent Genetics, Hyderabad	180-210 (medium)	70-73	112-115
Inbred (Variety)					
CSV 15	SPV475 × SPV462	1996, DSR, Hyderabad	240-260 (tall)	69-70	110-115
CSV 17	SPV946 × SPV772	2002, MPUAT, Udaipur	135-150 (short)	55-60	97-100
CSV 20	SPV946 × Kh 89-246	2006, DSR, Hyderabad	250-270 (tall)	70-72	105-110
CSV 23	SPV 861 × SU 248	2007; MPUAT, Udaipur	230-250 (tall)	70-72	110-115
SPV 462	(IS 2947 × SPV 232) × 1022	RARS, Palem	235-250 (tall)	70-73	112-115

NA: Not available; DSR: Directorate of Sorghum Research; PDKV: Panjabrao Deshmukh Krishi Vidyapeeth; MPUAT: Maharana Pratap University of Agriculture and Technology.

Table 2 Effect of weed control and genotypes on density and dry matter of weeds (Mean of two years)

Treatment	Weed density (No/m²)			
	Broad-leaved	Grasses	Sedges	Total
Weeding regime				
Unweeded check	56	16	7	79
Weeded once	25	6	10	41
Weeded twice	12	3	3	18
LSD (P=0.05)	6	2	2	5
Cultivar				
CSH 16	27	5	10	42
CSH 23	32	13	6	51
CSH 14	33	15	5	53
SPH 1596	24	5	6	35
SPH 1606	29	6	4	39
SPH 1616	33	10	7	50
CSV 15	18	13	6	37
CSV 17	58	10	8	76
CSV 20	30	5	8	43
CSV 23	23	5	8	36
SPV 462	31	4	5	40
LSD (P=0.05)	8	3	2	6

W, Weeding regime; C, cultivar

relative density of broad-leaved weeds was higher (70.9%) compared to grasses (20.3%) and sedges (8.8%). The dominant broad-leaved weeds associated with grain sorghum were parthenium (*Parthenium hysterophorus* L.) (24.7%), puncturevine (*Tribulus terrestris* L.) (11.9%), pill pod spurge (*Euphorbia hirta* L.) (8.77%), false amaranth (*Digera arvensis* Forsk.) (7.15%), and East Indian Jew's mallow (*Corchorus acutangulus* Lam.) (6.1%); grass weed species included crowfoot grass [*Dactyloctenium aegyptium* (L.) Willd.] (10.07%) and crab grass [*Digitaria sanguinalis* (L.) Scop.] (8.06%); and sedges such as purple nutsedge (*Cyperus rotundus* L.) (5.6%). Other minor weeds of grain sorghum included broad-leaved such as pigweed (*Amaranthus viridis* L.), horse purslane (*Trianthema portulacastrum* L.), sessile joyweed [*Alternanthera sessilis* (L.) DC.], and spreading dayflower (*Cyanotis axillaris* Roem. & Schult. F.); grasses such as browntop millet [*Brachiaria ramosa* (L.) Stafp.], peacock plume grass (*Chloris barbata* Sw.), jungle rice [*Echinochloa colona* (L.) Link.], wiper grass [*Dinebra retroflexa* (Vahl.) Panzer], and tarpedo grass (*Panicum repens* L.).

Weed density differed significantly ($P<0.05$) among weeding levels and cultivars (Table 2). The total weed density was lowest (18 plants/m²) in plots weeded twice, compared to plots weeded once (41 plants/m²) or kept weedy (79 plants/m²). Weeding once resulted in a higher number of *C. rotundus* (10 plants/m²) as compared to unweeded check (7 plants/m²) due to fast regeneration of fragmented rhizomes in absence of competition from other weeds. Among cultivars, total weed density ranged from 35 to 76 plants/m² with the lowest weed density observed under SPH 1596 (35 plants/m²) and the highest with CSV 17 (76 plants/m²).

Average weed dry weight was higher in 2010 (174 g/m²) than in 2009 (127 g/m²). Higher rainfall (947.5 mm) and number of rainy days (55) favoured the weed growth during 2010 compared to 2009 (601.2 mm and 33 days). Weeding reduced weed dry weight substantially with the lowest weed dry weight in plots weeded twice during both the years (Table 3). Whereas weeding once was very effective in 2009 and resulted in 75% reduction in weed dry weight compared to weedy check, it was less effective in 2010 and reduced only 55% weed dry matter. Across the cultivars, average weed dry weight was 18.25 times lower in the plots weeded twice than in the weedy plots during 2009 and 6.83 times during 2010. Less effectiveness of weeding during

Table 3 Interaction effects of weeding levels and cultivars on weed dry weight (g/m²) at harvest

Cultivar	2009				2010			
	Weedy check	Weeded once	Weeded twice	Mean	Weedy check	Weeded once	Weeded twice	Mean
CSH 16	264	45	7	105	312	101	30	148
CSH 23	272	24	4	100	342	140	40	174
CSH 14	355	109	18	161	385	156	44	195
SPH 1596	271	72	28	123	295	108	22	142
SPH 1606	309	51	18	126	324	112	41	159
SPH 1616	304	61	10	125	334	126	35	165
CSV 15	240	43	14	99	264	193	67	175
CSV 17	365	147	30	181	388	264	75	242
CSV 20	261	109	20	130	323	145	50	173
CSV 23	325	69	12	136	346	130	54	177
SPV 462	243	67	10	107	298	144	66	169
Mean	292	73	16		328	147	48	
LSD (P=0.05)	W=24	C=61	W×C=ns		W=27	C=27	W×C=ns	

W, Weeding regime; C, cultivar

Table 4 Interaction effects of weeding levels and cultivars on grain yield (kg/ha)

Cultivar	2009					2010				
	Weedy check	Weeded once	Weeded twice	Mean	Reduction*	Weedy check	Weeded once	Weeded twice	Mean	Reduction*
CSH 16	2 954	3 810	3 813	3 526	22.53	2 339	3 215	3 669	2 241	36.25
CSH 23	2 032	3 511	3 713	3 085	45.27	1 845	2 905	3 436	2 729	46.30
CSH 14	2 360	3 252	3 568	3 060	33.86	2 104	3 082	3 561	2 916	40.92
SPH 1596	2 037	3 560	3 970	3 189	48.69	2 037	3 295	3 839	3 057	46.94
SPH 1606	2 160	3 211	3 772	3 048	42.74	2 070	3 163	3 652	2 962	43.32
SPH 1616	2 218	3 476	3 958	3 217	43.96	2 153	3 483	3 736	3 124	42.37
CSV 15	1 995	2 893	3 629	2 839	45.03	1 574	2 347	2 800	2 240	43.79
CSV 17	1 321	1 569	2 030	1 640	34.93	1 093	1 211	1 671	1 325	34.59
CSV 20	1 413	1 678	2 257	1 783	37.39	1 455	1 748	2 128	1 777	31.63
CSV 23	1 441	2 651	2 935	2 342	50.90	1 337	2 543	2 846	2 242	53.02
SPV 462	1 942	2 369	2 447	2 253	20.64	1 606	2 413	2 841	2 287	43.47
Mean	1 988	2 907	3 281			1 783	2 673	3 107		
LSD (P=0.05)	W=413	C=608	WxC =ns			W=369	C=784	WxC = ns		

*Reduction in sorghum grain yield= [(Weeded twice-Weedy check)/Weeded twice] × 100. DAS, Days after sowing, ns, non-significant, W, weeding regime, C, cultivar.

2010 was attributed to the higher weed growth owing to favourable weather conditions for weed growth. There were significant differences among cultivars in their ability to reduce weed dry weight. Among hybrids the lowest weed dry weight (264 g/m^2) was recorded under CSH 16 which was 25.6% lower as compared to CSH 14 (355 g/m^2) in unweeded plot during 2009, whereas in 2010 SPH 1596 (295 g/m^2) had 23.4% less weed dry weight compared to CSH 14 (385 gm^2). Among the varieties CSV 15 had the lowest weed dry weight during both the years which was 32% lower than CSV 17. Because of the lowest plant height and LAI, and the highest LTR, CSV 17 had the maximum weed dry weight during both the years. Overall among all the 11 cultivars evaluated, CSV 15 had the lowest weed dry weight in unweeded plot during both the years. The cultivar competitiveness was associated with its ability to intercept solar radiation. Thus, the sorghum leaf area index (LAI), light transmission ratio (LTR), number of panicles/m^2 and plant height were negatively correlated with weed biomass

Table 5 Correlations among fresh shoot weight, grain yield, leaf area index, light transmission ratio, panicle length, panicle number, plant height, 100-seed weight and weed dry weight for grain sorghum cultivars

Parameters	FSW	GY	LAI	LTR	PL	PN	PH	SW
GY	0.61*							
LAI	0.46	0.84**						
LTR	-0.43	-0.77	-0.82**					
PL	0.53	0.54	0.61	-0.52				
PN	0.26	0.68	0.72**	-0.65*	0.48			
PH	-0.13	0.21	0.44	-0.57*	0.25	0.47		
SW	0.58*	0.35	0.38	-0.13	0.54*	0.25	-0.06	
WDW	-0.09	-0.62*	-0.81**	0.56*	-0.40	-0.71**	-0.51	-0.21

*Significant at the 0.05 level, **Significant at the 0.001 level. FSW, Fresh shoot weight at 15 days after sowing (DAS); GY, grain yield of sorghum; LAI, leaf area index at 60 DAS; LTR, light transmission ratio; PL, panicle length; PN, panicle number; PH, plant height at maturity; SW, 100-seed weight; WDW, weed dry weight at harvest.

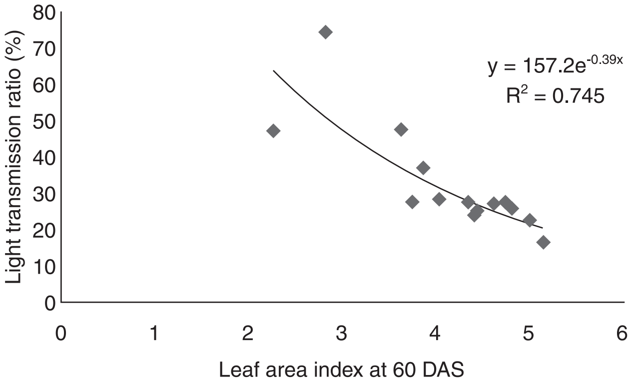

Fig 1 Relationship between leaf area index at 60 days after sowing and light transmission ratio

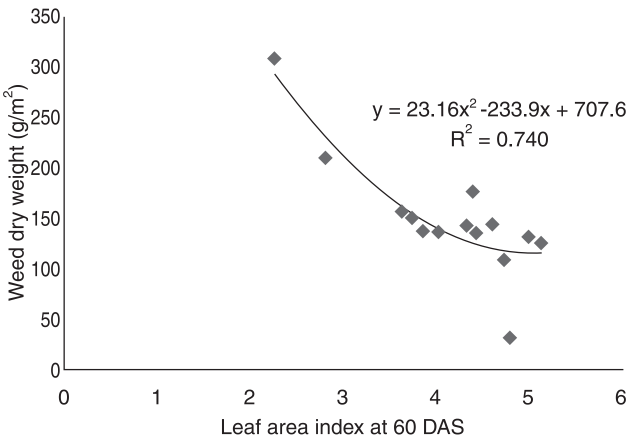

Fig 2 Relationship between leaf area index at 60 days after sowing and weed dry weight (g/m^2)

(Table 5). Irrespective of the weeding levels and cultivars, sorghum LAI measured at 60 DAS was negatively correlated with LTR (r= –0.82**) and weed dry weight at harvest (r= –0.81**). This relationship has been illustrated in Fig 1 and Fig 2. Higher LAI and lower LTR under CSH 16, SPH 1596 and CSV 15 (Table 6) are probably responsible for the lower weed dry weight. By absorbing light in the canopy, these genotypes reduced light penetrating into weeds resulting in lower weed dry matter production. High leaf area index and increased level of shading resulted in decreased weed biomass and weed seed production in sorghum (Traore *et al.* 2003).

Sorghum growth and yield attributes

Weeding levels and cultivars differed significantly on their effects on sorghum growth (root length, shoot weight, plant height, LAI) and yield attributes (number of panicles/m^2, panicle length, 100 seed weight) (Table 6). Root length and shoot weight taken at 15 DAS did not differ significantly due to the weeding regime as the first weeding was done at 30 DAS. Among the cultivars, hybrids had the shorter root length than the varieties, but the shoot weight was higher in the hybrids. Among the varieties, CSV 15 had the longest roots (11.34 cm) followed by SPV 462 (10.46 cm). CSH 16 among the hybrids and CSV 15 among the varieties had the maximum shoot weight. Sorghum height at harvest and LAI at 60 DAS did not differ between weeded once and twice. Among hybrids CSH 16 grew taller (195 cm) and accumulated higher LAI (5.15) and lower LTR (16.85) than others, which may contribute to its superior weed competitive ability. Plant height was negatively correlated with weed dry weight (r= –0.51). Among the varieties, although CSV 15 grew 34 cm shorter than CSV 20, it produced higher LAI and intercepted more solar radiation and suppressed the weed growth. Sorghum variety CSV 17, being shorter in the height (135 cm) and least in the LAI (2.82) had the maximum LTR (74.71%). Unweeded check significantly reduced the number of panicles, panicle length and the 100-grain weight as compared to weeded twice. Weed dry weight was significantly and negatively correlated with panicle number (r= –0.71**), whereas the LAI was positively correlated (r=0.72**). Reduction in number of panicles in the weedy

Table 6 Effect of treatment on growth and yield attributes of grain sorghum (mean of 2 years)

Treatment	Root length (cm)	Shoot weight (g/ plant) at 15 DAS		Plant height (cm)				Leaf area index			Light trans-mission ratio (%)	Panicles m^2 at harvest	Panicle length (cm)	100-grain weight (g)
		Fresh	Dry	15 DAS	30 DAS	60 DAS	Harvest	15 DAS	30 DAS	60 DAS				
Weeding regime														
Weedy check	9.50	0.577	0.067	5.19	36.46	58.61	162	0.026	1.20	2.27	47.62	10.16	24.88	2.48
Weeded once	9.82	0.556	0.065	5.48	36.63	62.95	184	0.028	1.41	4.75	27.84	11.71	26.72	2.69
Weeded twice	10.19	0.511	0.068	5.47	44.19	62.51	187	0.028	1.52	4.82	26.01	12.19	26.99	2.69
LSD (P=0.05)	ns	ns	ns	ns	3.28	1.81	9	0.001	0.08	0.85	3.88	0.90	1.98	0.16
Cultivar														
CSH 16	7.62	0.90	0.115	5.60	36.91	65.64	195	0.035	1.50	5.15	16.85	12.39	30.23	2.96
CSH 23	7.62	0.61	0.070	5.30	35.04	61.31	165	0.029	1.24	4.04	28.82	12.25	27.27	2.46
CSH 14	8.58	0.527	0.077	4.99	43.04	63.09	166	0.027	1.14	4.41	24.25	10.80	25.18	2.51
SPH 1596	8.63	0.533	0.0758	5.12	34.69	59.96	171	0.27	1.63	5.01	22.87	11.63	27.16	2.96
SPH 1606	8.56	0.549	0.071	4.6	36.2	61.38	164	0.29	1.32	4.35	27.95	10.85	26.56	2.89
SPH 1616	7.98	0.584	0.076	5.23	37.5	62.36	170	0.27	1.26	4.62	27.48	12.01	27.62	2.72
CSV 15	11.34	0.430	0.053	5.26	30.59	63.67	171	0.017	1.23	4.44	25.59	11.62	24.19	2.25
CSV 17	9.63	0.409	0.048	5.42	32.28	59.70	135	0.028	1.12	2.82	74.71	9.80	25.31	2.67
CSV 20	8.22	0.358	0.046	5.0	28.23	58.98	205	0.017	1.01	3.87	37.42	10.86	25.46	2.28
CSV 23	10.46	0.393	0.047	4.8	42.13	60.22	180	0.030	1.57	3.64	47.95	12.01	23.66	2.81
SPV 462	9.97	0.367	0.052	5.68	40.59	58.62	193	0.017	1.61	3.75	28.15	11.03	25.67	2.55
LSD (P=0.05)	0.88	0.106	0.005	0.39	6.12	ns	25	0.002	0.21	1.41	5.27	1.18	2.49	0.26

DAS, Days after sowing; ns, non-significant

Table 7 Effect of weeding levels and cultivars on economic returns (mean of 2 years)

Cultivar	Net income (₹/ha)				B:C			
	Weedy check	Weeded once	Weeded twice	Mean	Weedy check	Weeded once	Weeded twice	Mean
CSH 16	15 444	18 924	16 640	17 002	2.47	2.22	1.83	2.17
CSH 23	8 483	15 933	15 009	13 142	1.81	2.03	1.75	1.86
CSH 14	11 365	15 553	14 955	13 958	2.08	2.00	1.75	1.94
SPH 1596	9 462	18 108	18 272	15 280	1.90	2.17	1.91	1.99
SPH 1606	10 223	15 716	16 368	14 102	1.97	2.02	1.82	1.94
SPH 1616	10 930	18 598	17 674	15 734	2.04	2.20	1.89	2.04
CSV 15	7 178	10 386	11 692	9 752	1.70	1.68	1.59	1.66
CSV 17	1 523	–1 686	–1686	–616	1.15	0.89	0.92	0.98
CSV 20	3 752	1 468	1686	3 202	1.36	1.10	1.09	1.18
CSV 23	3 317	10 169	8 538	7 341	1.32	1.66	1.43	1.47
SPV 462	7 069	8 157	6 091	7 106	1.69	1.53	1.31	1.51
Mean	8 483	11 939	11 385		1.77	1.77	1.57	
LSD (P=0.05)	W=1 033	C=1 522	W×C=sig.		W=0.03	C=0.03	W×C=sig.	

check plot was attributed to the plant mortality due to severe weed competition. CSH 16 had the maximum number of panicles/m^2 (12.39) and CSV 17, the minimum (9.80). The hybrid CSH 16 produced significantly bolder seeds as compared to other cultivars. Initial fresh shoot weight (r=0.58*) and panicle length (r=0.54*) were significantly positively correlated with 100-grain weight). Interactions of weeding levels × cultivars were not significant for these attributes.

Grain yield

Irrespective of the treatments, sorghum grain yield was higher during 2009 than 2010 mainly due to reduced weed competition (Table 4). Averaged across cultivars, plots weeded once produced 46% more grain yield in 2009 and 50% in 2010 than unweeded check. Following two weedings, the increase in grain yields over the unweeded plots was 65% in 2009 and 74% in 2010. The difference in yield between weeding once and twice was 374 kg/ha in 2009 and 434 kg/ha in 2010. Hybrids produced a higher grain yield than varieties during both the years. In 2009, CSH 16 (among hybrids) and CSV 15 (among varieties) with one weeding, and SPH 1596 (hybrid) and CSV 23 (variety) with 2 weedings produced the most grain. However in 2010, SPH 1616 weeded once and SPH 1596 weeded twice produced the maximum grain yields among hybrids. Among the varieties CSV 23 produced the highest grain yield under both weeding frequencies. Under high weed pressure (unweeded control), CSH 16 (among hybrids) and CSV 15 and SPV 462 (among varieties) had a higher grain yield during both the years. Because of the higher LAI and the lower LTR, CSH 16 resulted in better suppression of the weed growth as compared to other hybrids and produced more grain yield under unweeded condition. The yield reduction due to weed competition among cultivars varied from 20.6 to 50.9% in 2009 and 31.6 to 53% in 2010. Despite the higher weed dry weight, the CSH 14, SPH 1616 and SPH 1606 had higher grain yields than SPH 1596 under unweeded conditions, suggesting that they tolerated higher weed pressure. Among the varieties, CSV 15 and SPV 462 suppressed the weed growth and produced higher yields than others. Sorghum variety CSV 17 had the lowest grain yield irrespective of the weeding regime and year because of its weaker weed suppressive ability and low yield potential.

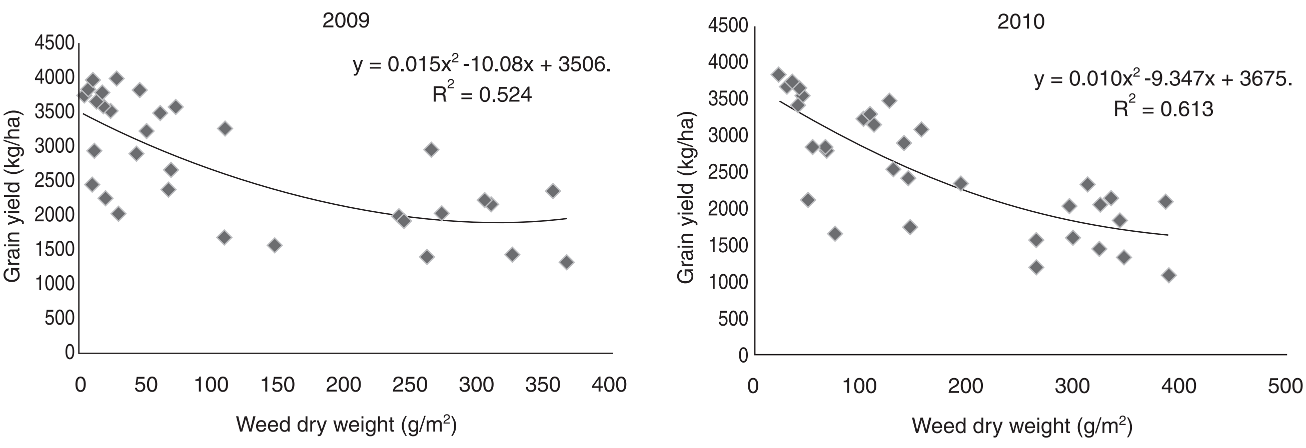

Fig 3 Relationship between grain yield (kg/ha) and weed biomass (g/m^2) at crop harvest

Cultivar-weed competitiveness is a complex attribute that involves the ability of the cultivar to maintain yields despite the high weed pressure (weed tolerance) and the ability to suppress weed growth (Jannik *et al.* 2000). Weed suppressive ability reduces weed seed production and benefits weed management in the long-term, while weed tolerance only benefit yield in the current growing season and may result in increased weed pressure in the future. However, strong weed suppressive ability does not guarantee a high yield under weed competition if the yield potential is low (Zhao *et al.* 2006).

Grain yield was significantly and positively correlated with initial fresh shoot weight (r= 0.61*), LAI (r= 0.84**), panicle number (r= 0.68**), and significantly negatively correlated with weed biomass (r= –0.62*) and LTR (r= –0.77**). There was a negative linear relationship between weed dry weight and grain yield. The effect of increasing weed dry weight on reduction in grain yield was more pronounced in hybrids than in varieties (Fig 3).

Economic analysis

In general, the plots weeded once had 48% higher net income than the unweeded control. Hybrids paid more net income than the varieties (Table 7). Among hybrids, CHS 16' in weedy plots and at one weeding, and SPH 1596 at 2 weedings had the highest net income and benefit: cost (B:C). Among the varieties, CSV 17 had the highest net income, irrespective of the weeding levels. Weeding with CSV 17 was not at all economical because of its poor yields. CSH 16 in the weedy plots had the highest B:C (2.47) because of its higher yields and weed suppressing ability. The sale prices for different cultivars used were the same, thus, the difference in net income was largely due to variation in yield levels and cost of weeding.

The results of our study revealed that sorghum hybrids had higher yields and economic returns than the varieties. Hybrid CSH 16 had superior weed suppressing ability, while CSH 14, SPH 1616 and SPH 1606 had higher weed tolerance. The yield advantage and economic returns of CSH 16, SPH 1616 and SPH 1596 with one hoe weeding were higher. Hence, these hybrids could be recommended in the semi-arid tropical regions to avoid the costs on second weeding.

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