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Effect of integrated weed management practices on winter (*Rabi*) season sorghum (*Sorghum bicolor*)

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Abstract
A field experiment was conducted during *rabi*-2014,2015 and 2016 at Instructional farm, N. M College of Agriculture, N. A. U., Navsari, Gujarat. The study consisted of 12 treatments viz., Unweeded control, Weed free, Two hand weeding (HW) and interculturing (IC) at 20 & 40 DAS, Atrazine @ 0.5 kg ha-1 as pre-emergence (PE), Atrazine @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS, Atrazine @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS, Pendimethalin @ 0.5 kg ha-1 PE, Pendimethalin @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS, Pendimethalin @ 0.5 kg ha-1 PE + 2, 4-D @ 0.5 kg ha-1 post emergence (PoE) at 20 DAS, Atrazine @ 0.5 kg ha-1 PE + Pendimethalin @ 0.25 kg ha-1 PE (Tank mixture), Atrazine @ 0.5 kg ha-1 PE + 2, 4-D @ 0.5 kg ha-1 PoE at 20 DA, Atrazine @ 0.5 kg ha-1 PE + Pyrithiobac sodium @ 0.5 kg ha-1 PoE at 20 DAS, Organic mulch (Sugarcane trash @ 2 t ha-1, after germination of crop between row) were tested in randomized block design with three replications. The study identified application of atrazine @ 0.5 kg/ha as pre-emergence along with one hand weeding and interculturing at 20 DAS and followed by Two hand weeding (HW) and interculturing (IC) at 20 & 40 DAS) reduced weed competition, obtained better growth and produced higher yields along with more net monetary returns

Keywords: Sorghum, weed density, weeds dry weight, grain yield, straw yield, economics.

Introduction
Losses due to weeds have been one of the major limiting factors in sorghum production, most of the yield reduction due to weed competition occurs during the first six weeks after sowing. Presence of weeds during critical period reduced the yield of sorghum to the extent of 15-40% (Mishra 1997) [3]. Therefore major emphasis on weed control should be given during this period. Good sorghum weed control involves utilizing all methods available and combining them in an integrated weed management system. Integrated weed management (IWM), the process of combining several single management strategies together to suppress weeds has been developed (Gill *et al*., 1997) [4]. In south Gujarat, traditional hand weeding and mechanical weed control using implements is the most efficient and widely adopted practice of weed control in sorghum. But considering the present day labour scarcity and their higher wages for cultural and mechanical weed control, the economic feasibility of sorghum cultivation is quiet disturbed. Hence, the emphasis should be given to adopt the chemical methods of weed control. It is quick, more effective, time saving and to solve the problem of minimum available labour and their high cost. Continuous use of herbicides over a prolonged time leads to development of resistance in weeds making them difficult to control. In fact none of the weed control methods is best under all conditions. Hence, various components of integrated weed management was blended in a systemic way to achieve the acceptable level of weed control to make a comparative study of different weed management techniques in sorghum and to develop an integrated weed management approach, which should be efficient, cost effective and environmentally safe. Keeping these facts in view, a field trial was planned.

Materials and Methods
A field experiment was conducted during kharif season of 2014, 2015 and 2016 at Instructional farm, N. M College of Agriculture, N. A. U., Navsari, Gujarat. The soil of the experimental site clayey in texture and PH was high (7.8). The soil was low in available nitrogen (191 kg/ha), medium in available phosphorus (34 kg/ha) and high in available potassium (592 kg/ha). Experiment consisting 12 treatments i. e., T_1: Unweeded control, T_2:

Weed free, T_3: Two hand weeding (HW) and interculturing (IC) at 20 & 40 DAS, T_4: Atrazine @ 0.5 kg ha-1 as pre-emergence (PE), T_5: Atrazine @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS, T_6: Pendimethalin @ 0.5 kg ha-1 PE, T_7: Pendimethalin @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS, T_8: Pendimethalin @ 0.5 kg ha-1 PE + 2, 4-D @ 0.5 kg ha-1 post emergence (PoE) at 20 DAS, T_9: Atrazine @ 0.5 kg ha-1 PE + Pendimethalin @ 0.25 kg ha^{-1} PE (Tank mixture), T_{10}: Atrazine @ 0.5 kg ha-1 PE + 2, 4-D @ 0.5 kg ha-1 PoE at 20 DA, T_{11}: Atrazine @ 0.5 kg ha-1 PE + Pyrithiobac sodium @ 0.5 kg ha-1 PoE at 20 DAS, T_{12}: Organic mulch (Sugarcane trash @ 2 t ha-1, after germination of crop between row). These treatments were replicated three times in a randomized block design. Main field was prepared by two dry ploughing at an interval of 10 to 15 days followed by passing the harrow and leveler. The seeds of GJ-38, popular duration variety 15 kg/ha was sown at the spacing of 45 cm X 15 cm. The recommended dose of fertilizer 80: 40:00 kg NPK ha^{-1} was applied. Full dose of P_2O_5 and K_2O was applied at the time of sowing by using single super phosphate and murate of potash, respectively. The 40 per cent of nitrogen was applied as a basal, 40 percent at 40 DAS and remaining 20 per cent at 45 DAS.

The observation on plant height, length of earhead, No. of grains per earhead and testweight, grain and straw yields, weed density and weed dry weight were recorded at harvest. Since the data on weed density and weed dry weight showed high variation, the data were subjected to square root transformation and the statistical analysis was done. Weed index and weed control efficiency were calculated as per the standard formulae.

$$\text{Weed control efficiency} = \frac{\text{Dry matter production of weed in unneeded plot - Dry weight production of weeds in treated plot}}{\text{Dry matter production of weed in unneeded plot}} \times 100$$

$$\text{Weed control index} = \frac{\text{Yield from weed free plot-Yield from treatment plot}}{\text{Yield from weed free plot}} \times 100$$

Results and Discussion

The major weeds infested with the experimental field were *Echinochloa crusgalli, Echinochloa colonum, Digitaria sanguinalis* and *Eleusine indica* among grassy weeds and *Portulaca oleracea, Amaranthus viridis, Acalypha indica, Ageratum conyzoides, Euphorbia geniculata, Digera arvensis, Phyllanthus niruri, Eclipta alba* and *Phyllanthus maderaspatensis* among broad leaf weeds and *Cyprus rotundus* among sedges.

Weed density (No. m^2) and Weed dry weight (g/m^2)

The weed count and weed dry weight was taken during all the years and results are presented in Table 1. In three years pooled results, significantly lower weed count was registered in treatment T_2 (Weed free) than other treatments. The next best to treatment T_2 was T_3, significantly lower down the weed count but which was remained at par with treatment T_5. (Table 1).

Significant variation in weed dry weight existed between treatments (Table 1) differences at harvest. The significantly lowest (1.35 g/m^2) weed dry weight resulted from T_2 i.e. weed free during in pooled results than rest of the treatments. The next best treatment was T_5, but which remained at par with treatment T_7 in pooled results. This may be because of effective control of weeds by different weed management practices.These results corroborate the findings of Thakur *et al*. (2016) [1].

Weed control efficiency and weed index

Weed-control efficiency of different weed-management practices varied from 74.26 to 51.01.01%, maximum (74.26%) was recorded with application of Atrazine @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS) followed by Two hand weeding (HW) and interculturing (IC) at 20 & 40 DAS)

The lower weed index (6.28%) was recorded with T_5 (Atrazine @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS) followed by T_3 (Two hand weeding (HW) and interculturing (IC) at 20 & 40 DAS). This was mainly due to better control of weed growth even up to harvest resulting in lower dry weight of weeds. (Table 1).

Table 1: Effect of weed management treatments on total weeds, weed dry weight (gm^2), Weed index (%) and weed control efficiency (%). (Pooled of three years).

	Treatments	Weed density (No./ m^2)	Weed dry weight (g/m^2)	Weed index (%)	Weed control efficiency (%)
T_1	Unweeded control	7.52 (56.67)	8.29 (68.93)	37.99	-
T_2	Weed free	1.81 (3.75)	1.35 (1.90)	-	97.24
T_3	Two hand weeding (HW) and interculturing (IC) at 20 & 40 DAS	4.45 (20.00)	4.25 (18.33)	6.31	73.41
T_4	Atrazine @ 0.5 kg ha-1 as pre-emergence (PE)	5.57 (31.17)	5.61 (31.67)	22.74	54.05
T_5	Atrazine @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS	4.46 (20.08)	4.15 (17.74)	6.28	74.26
T_6	Pendimethalin @ 0.5 kg ha-1 PE	5.74 (33.00)	6.02 (36.50)	24.50	47.05
T_7	Pendimethalin @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS	4.79 (23.17)	4.59 (21.21)	10.29	69.23
T_8	Pendimethalin @ 0.5 kg ha-1 PE + 2, 4-D @ 0.5 kg ha-1 post emergence (PoE) at 20 DAS	5.44 (29.75)	5.31 (28.45)	20.15	58.73
T_9	Atrazine @ 0.5 kg ha-1 PE + Pendimethalin @ 0.25 kg ha-1 PE (Tank mixture)	5.46 (30.00)	5.42 (29.52)	13.55	57.17
T_{10}	Atrazine @ 0.5 kg ha-1 PE + 2, 4-D @ 0.5 kg ha-1 PoE at 20 DAS	5.48 (30.08)	5.49 (30.38)	17.76	55.93
T_{11}	Atrazine @ 0.5 kg ha-1 PE + Pyrithiobac sodium @ 0.5 kg ha-1 PoE at 20 DAS	5.09 (26.00)	5.15 (26.73)	65.61	61.22
T_{12}	Organic mulch (Sugarcane trash @ 2 t ha-1, after germination of crop between row)	5.98 (35.92)	5.79 (33.77)	32.98	51.01
	S. Em $\pm$	0.11	0.11		
	C.D. at 5 %	0.32	0.31	-	-
	C.V. (%)		8.10		

* Figures indicating ($\sqrt{X + 0.5}$) transformed values, Figures in parenthesis are indicating original values. NA - Not analyzed

Effect on crop growth

The pooled results pertaining to the growth parameters like plant height and number of internodes per plant are reported in Table 2. Among the different weed management treatments, T_2 *i.e.* weed free recorded significantly higher plant height (202.5 cm), but it remained at par with T_3 and T_5. Similarly, number of internodes per plant were also recorded higher under T_2 *i.e.* weed free (9.9), but which was remain at par with T_3, T_5 and T_7.

Effect on yield attributes

The results of the experiment indicated that different weed management treatments had significant effect on yield attributes of sorghum during all the years as well as in pooled results. In pooled analysis, the yield attributes *viz*., length of earhead, No. of grain per earhead, grain weight per earhead and thousand grain weight were affected significantly due to different weed management practices.

The treatment T_2 *i.e.* weed free recorded significantly higher values (30.6 cm) length of earhead which was at par with treatment T_3, T_5, T_7 and T_9. Similarly, No. of grains per earhead (1004) and grain weight per earhead were (24.8 g) also recorded more under same treatment, but which remained at par with treatment T_5, T_3 and T_7. In case of thousand grain weight, same treatment T_2 *i.e.* weed free recorded significantly higher thousand grain weight (24.5 g) but, it was at par T_3, T_7, T_5, T_9, T_{10}, T_8 and T_6. (Table 2) This may be because of lesser weeds were observed in these treatments, which may have resulted in increased nutrient, water, space and light supply to sorghum crop due to absence of crop-weed competition.

Effect on grain and straw yield

The results of the experiments indicated that the different weed management treatments had significant effect on grain and straw yield of sorghum during all the years as well as in pooled results. Significantly higher grain yield (Table 2) was recorded with treatment T_2 *i.e* weed free but which was at par with treatments T_3, T_5, T_7 and T_9 during all the years of investigation. However, treatment T_7 and T_9 failed to exert their significant effect in pooled results. Among the different weed management treatments, T_5 showed superiority over other but it was at par with T_3, T_7 and T_9 in all the years. On pooled basis, the treatments T_5 (3251 kg/ha), T_3 (3250 kg/ha), T_7 (3112 kg/ha), T_9 (2999 kg/ha) and T_{10} (2853 kg/ha) were at par with each other. The phytoxicity observed in sorghum and treatment T_{11} lead to lower grain yield (1193 kg/ha) due to the post emergence application of pyrithiobac sodium @ 0.5 kg/ha at 20 DAS.

In case of straw yield, the maximum straw yield (9396 kg/ha) was recorded with treatment T_2 and remained at par with T_3, T_5 and T_7 registered 8898, 8813, 8673 kg/ha of sorghum straw yield. (Table 2). This may be due to cumulative effect of reduced weed competition and higher value of yield attributes. This is in conformity with the findings of Kausik and Shaktawat (2005) [2], Satheeshkumar *et al.* (2011), Thakur *et al*. (2016) [1] and (Mundra *et al*., 2003) [5].

Table 2: Effect of weed management treatments on growth and yield of sorghum (Pooled of three years).

Treatments		Plant height (cm)	No. of internodes/ plant	Length of earhead (cm)	No. of grains/ earhead	Grain weight/ earhead (g)	1000 Grain Weight (g)	Grain Yield (kg/ha)	Straw Yield (kg/ha)
T_1	Unweeded control	152.4	7.4	21.5	798	16.5	21.4	2151	6146
T_2	Weed free	202.5	9.9	30.6	1004	24.8	24.5	3469	9396
T_3	Two hand weeding (HW) and interculturing (IC) at 20 & 40 DAS	197.5	9.8	29.9	960	23.6	24.4	3250	8898
T_4	Atrazine @ 0.5 kg ha-1 as pre-emergence (PE)	174.4	8.6	25.7	837	19.7	23.9	2680	7406
T_5	Atrazine @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS	192.9	9.5	29.8	971	23.9	24.3	3251	8813
T_6	Pendimethalin @ 0.5 kg ha-1 PE	171.2	8.4	25.5	830	19.4	23.7	2619	7194
T_7	Pendimethalin @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS	189.0	9.4	29.1	948	23.4	24.4	3112	8673
T_8	Pendimethalin @ 0.5 kg ha-1 PE + 2, 4-D @ 0.5 kg ha-1 post emergence (PoE) at 20 DAS	179.8	8.8	28.6	859	20.4	23.9	2770	8035
T_9	Atrazine @ 0.5 kg ha-1 PE + Pendimethalin @ 0.25 kg ha-1 PE (Tank mixture)	184.5	9.3	29.0	908	22.4	24.1	2999	8462
T_{10}	Atrazine @ 0.5 kg ha-1 PE + 2, 4-D @ 0.5 kg ha-1 PoE at 20 DAS	185.1	9.1	28.3	873	21.1	24.0	2853	8318
T_{11}	Atrazine @ 0.5 kg ha-1 PE + Pyrithiobac sodium @ 0.5 kg ha-1 PoE at 20 DAS	124.3	5.8	20.1	568	12.3	21.1	1193	4289
T_{12}	Organic mulch (Sugarcane trash @ 2 t ha-1, after germination of crop between row)	168.4	8.3	24.3	826	18.8	23.1	2325	6435
	S. Em ±	3.41	0.18	0.59	20.08	0.45	0.33	106	280
	C.D. at 5 %	9.56	0.49	1.65	56.24	1.27	0.94	299	784
	C.V. (%)	7.13	7.41	8.19	8.68	8.21	5.38	14.42	13.58

Economics

The different weed management treatments recorded varying net income realized due to sorghum. The net realization of Rs. 37108 /ha was recorded with treatment T_5 which was followed by T_3 (36363 /ha), T_7 (34310 /ha) and T_9 (33810 /ha). The maximum B:C ratio of 2.27 was obtained due to application of T_5 (Atrazine @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS) followed by T_9 (Atrazine @ 0.5 kg ha-1 PE + Pendimethalin @ 0.25 kg ha-1 PE (Tank mixture) and T_3 (Two hand weeding and interculturing at 20 and 40DAS) (Table 3) This is in conformity with the findings of Upadhyay *et al.* (2011).

Table 3: Cost and return analysis of different weed management treatments

Treatments		Fixed cost (Rs./ha)	Treatment cost (Rs./ha)	Total cost (Rs./ha)	Gross income (Rs./ha)	Net returns (Rs./ha)	B:C ratio
T_1	Unweeded control	26983	0	26983	44557	17574	1.65
T_2	Weed free	26983	8160	35143	70827	35684	2.02
T_3	Two hand weeding (HW) and interculturing (IC) at 20 & 40 DAS	26983	3200	30183	66546	36363	2.20
T_4	Atrazine @ 0.5 kg ha-1 as pre-emergence (PE)	26983	700	27683	55012	27329	1.99
T_5	Atrazine @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS	26983	2300	29283	66391	37108	2.27
T_6	Pendimethalin @ 0.5 kg ha-1 PE	26983	1133	28116	53673	25557	1.91
T_7	Pendimethalin @ 0.5 kg ha-1 PE + One HW & IC at 20 DAS	26983	2733	29716	64026	34310	2.15
T_8	Pendimethalin @ 0.5 kg ha-1 PE + 2, 4-D @ 0.5 kg ha-1 post emergence (PoE) at 20 DAS	26983	1623	28606	57620	29014	2.01
T_9	Atrazine @ 0.5 kg ha-1 PE + Pendimethalin @ 0.25 kg ha-1 PE (Tank mixture)	26983	1116	28099	61909	33810	2.20
T_{10}	Atrazine @ 0.5 kg ha-1 PE + 2, 4-D @ 0.5 kg ha-1 PoE at 20 DAS	26983	1190	28173	59431	31258	2.11
T_{11}	Atrazine @ 0.5 kg ha-1 PE + Pyrithiobac sodium @ 0.5 kg ha-1 PoE at 20 DAS	26983	1940	28923	26473	-2450	0.92
T_{12}	Organic mulch (Sugarcane trash @ 2 t ha-1, after germination of crop between row)	26983	1600	28583	47745	19162	1.67

Note- Sorghum grain: Rs.15.00/kg, Straw: Rs. 2.00 Rs. /kg, Atrazine 50 % WP: Rs.400/kg, Pendimethalin 30% EC: Rs. 500/kg, 2, 4-D sodium salt 80% WP: Rs.304/kg, Pyrithiobac sodium 10% Ec: Rs.1750/lit.

Conclusion

Based on the results of three years experimentation for effective management of weeds in *rabi* sorghum, application of atrazine @ 0.5 kg/ha as pre-emergence along with one hand weeding and interculturing at 20 DAS reduced weed competition, obtained better growth and development and produced higher yields (3251kg/ha) along with more net monetary returns (Rs. 37108/ha) followed by treatment T3 (Two hand weeding (HW) and interculturing (IC) at 20 & 40 DAS) produced higher yields (3250 kg/ha) along with more net monetary returns (Rs.36363/ha)While, the low cost weed management practice and taking into consideration the problem of availability of labour during weeding operation and convenience of farmers, the treatment T_9 i.e. atrazine @ 0.5 kg ha-1 + pendimethalin @ 0.25 kg ha-1 applied as pre-emergence in tank mixture found to reduce the weed competition in early growth stage of sorghum and gave the maximum monetary benefit (Rs. 33810 /ha) as compared to its cost of cultivation was found more viable.

Recommendation for the farmers

The farmers of south Gujarat heavy rainfall zone (AES III) growing *rabi* sorghum are advised to adopt two interculturing and handweeding at 20 & 40 DAS or atrazine @ 0.5 kg ha^{-1} as pre emergence (After sowing and before germination of crop and weed) and one interculturing and one hand weeding at 20 DAS for effective weed control, realizing higher grain and net income. Residue analysis of these herbicides were carried out and the doses were found below detectable level in grain and soil.

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