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Research Paper

Evaluation of different pre-and post-emergence herbicides on forage yield, quality and disease reaction of multi-cut forage sorghum (*Sorghum bicolor)*

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ABSTRACT

A field experiment was carried out during the rainy (*kharif*) seasons of 2013 and 2014 at Ludhiana, Punjab, to study the efficacy of different weed-management techniques on weed dynamics, fodder yield, quality and disease reaction in multi cut sorghum [*Sorghum bicolour* (L.) Moench]. The sorghum crop was infested with grassy, broad-leaf weeds and sedges, which reduced 28.1 and 32.7% of green-fodder and dry-fodder yields respectively. Hand-weeding (at 20 and 30 days after sowing) and application of atrazine @ 0.375 kg a.i./ha + pendimethalin @ 0.750 kg a.i./ha as pre-emergence spray significantly reduced total weed population and dry weight of weeds in comparison to the other weed-control treatments. These treatments showed higher weed-control efficiency (WCE) than that of the other weed-control treatments. Application of propaquizalofop as post-emergence spray was also effective in reducing weed population and dry matter but had phytotoxic effect on the crop and recorded significantly lower fodder yield. Hand-weeding resulted in significantly higher green-and dry-fodder yield of sorghum over all the treatments, but was statistically at par with the application of atrazine @ 0.375 kg a.i./ha + pendimethalin @ 0.750 kg a.i./ha as pre-emergence spray. These 2 treatments enhanced the green-fodder yield by 39.0 and 36.7% and dry-fodder yield by 48.5 and 45.1% respectively, over weedy check. Hand-weeding and application of atrazine + pendimethalin (0.375 + 0.750 kg a.i./ha) resulted in 58.7 and 53.9% more crude protein yield than weedy check respectively. The maximum net returns (₹37,790/ha and ₹36,320) and benefit: cost ratio (1.46 and 1.28) were realized with atrazine @ 0.375 kg a.i./ha + pendimethalin @ 0.750 kg a.i./ha (PE) and hand-weeding at 20 and 30 days after sowing respectively. The leaf-spot disease was the minimum (8.54 %) in hand weeded plots and plots sprayed with atrazine @ 0.375 kg a.i./ha + pendimethalin @ 0.750 kg a.i./ha as pre-emergence spray showed moderate leaf spot severity of 15.7% as the weed population was less in these plots.

Key words: Atrazine, Crude Protein, Forage sorghum, Leaf spots, Pendimethalin, Weeds

Sorghum is one of the important crops grown for cereal as well as for fodder throughout the world. The crop has the potentialities of being used solely either as food, feed or fodder. Its cultivation for fodder ensures availability of nutritious fodder during the lean period of the year and forage sorghum cultivation is emphasized owing to its drought-tolerant characteristics and high production potential. Weed causes more competitional stress to crop by taking essential nutrients, light, moisture and space. Uncontrolled weeds in sorghum depleted 29.9–51.1, 5.0–11.6 and 48.7–74.3 kg/ha N, P and K, respectively, from soil (Satao and Nalamwar, 1993). Weed competition substantially reduces the green forage yield and consequently, it causes reduction up to 30–40% besides deteriorating quality of green forage if not controlled during critical period of crop-weed competition. Moreover, weed population is conducive for the development of diseases which in turn affects the yield. Also the diseases such as leaf spots are the major hindrance in the sorghum crop which not only reduce the yield but also affects the quality of the crop. Therefore, there is a need to create an environment that is detrimental to weeds and favourable for the crops. Hence weed control needs to be restored during initial period of crop growth. Mechanical methods of weed control are very costlier and labour intensive. 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 (Ishaya *et al*., 2007). However, chemical weed control offers a better alternative to manual weeding being cost effective and labour saving. Keeping this in view, the

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present study was conducted to evaluate different pre- and post-emergence herbicides on forage yield, quality and prevalence of leaf spots of sorghum.

MATERIALS AND METHODS

A field experiment was conducted for the evaluation of different pre- and post-emergence herbicides during the rainy (*Kharif*) season of 2013 and 2014 at Forage Research Farm, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, (30.56° N, 75.52° E and 247 m above mean sea-level), situated in Trans-Gangetic Agro-Climatic Zone and represents the Indo-Gangetic Alluvial Plains. The climate of the area is characterized as subtropical and semi-arid with hot and dry spring-summer from April to June, hot and humid summer from July to September and cold autumn-winter from November to January. The maximum temperature above 38°C is common during summer months and frequent frosty spells with temperature as low as 1°C are experienced during winters, especially in December and January. The average annual rainfall is 705 mm, most of which is received during the monsoon period from July to September, while a few showers are received during the winter season. The soil was loamy sand with neutral *p*H (7.9), low in organic carbon (0.32%) and available nitrogen (253.9 kg/ha), medium in available phosphorus (21.1 kg/ha) and high in available potassium (332.0 kg/ha). The experiment was laid out in randomized complete block design in 3 replications with 12 treatments, viz. atrazine as pre-emergence (PE) application @ 0.5 kg a.i./ha, pendimethalin (PE) @ 0.75 kg a.i./ha, atrazine @ 0.25 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (PE), atrazine @ 0.375 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (PE), pinoxaden as post-emergence (PoE) application @ 0.0375 kg a.i./ha, pinoxaden (PoE) @ 0.05 kg a.i./ha, oxyflourfen (PE) @ 0.088 kg a.i./ha, oxyflourfen (PE) @ 0.176 kg a.i./ha, propaquizalofop @ 0.0625 kg a.i./ha (PoE), propaquizalofop @ 0.075 kg a.i./ha (PoE), hand-weeding at 20 and 30 day after sowing (DAS) and weedy check. The sorghum hybrid 'Punjab Sudax Chari 1' was sown in opened furrows, 30 cm apart, using seed rate of 37.5 kg/ha. A plant-to-plant distance of 10 cm was maintained by thinning and gap-filling operation at 15 days after sowing (DAS). Fertilizers were applied uniformly through urea and single superphosphate @ 100 kg N/ha and 20 kg P_2O_5/ha, respectively, to the first cut and 100 kg N/ha to subsequent cuttings. The crop was irrigated at 10-15 days interval as per the need during the summer season. Other agronomic and plant-protection measures were adopted as and when crop needed. The first cutting for fodder was taken at 55 DAS and subsequent cuttings at 40 days interval. Weed samples were collected randomly through placing of 50 cm × 50 cm quadrate in each plot from 3 places in each plot of treatment and weed population was recorded at the time of first cutting. Weeds were cut down at ground level and then identified, counted and the samples were kept in an oven at 70 ± 10°C until they attained constant weight. Growth and yield parameters were recorded after each cutting, and plant samples were dried for dry matter and crude protein estimation. Data on weed count were subjected to square-root transformation to normalize their distribution. The data for individual year were pooled and statistically analysed for interpretation of the results. The foliar leaf spot data were recorded by randomly selecting 100 leaf samples from the plots comprising 20 leaf sets from each corner of the plot and centre. The damage was further scored using 1–9 scale (Thakur *et al*., 2007) on the basis of per cent leaf area infected as 1: <1.0% infected area or isolated symptoms (Highly resistant, HR); 2: 1.0–5.0% infected area (Resistant, R); 3: 5.1–10.0% infected area (Resistant, R); 4: 10.1–20.0% infected area (Moderately Resistant, MR); 5: 20.1–30.0% infected area (Moderately Resistant, MR); 6: 30.1–40.0% infected area (Susceptible, S); 7: 40.1–50.0% infected area (Susceptible, S); 8: 50.1– 75.0% infected area (Highly Susceptible, HS); 9: > 75.0% infected area (Highly Susceptible, HS) and per cent disease index was calculated.

RESULUTS AND DISCUSSION

Weed flora

The experimental field during both years was infested with grassy weeds (46.8%), broad-leaf weeds (28.5%) and sedges (24.7%). The dominating weeds in sorghum were: *Acrachne racemosa, Digiteria sanguinalis, Eragrostis tenella, Dactyloctenium aegyptium, Eleucine indica* among grasses; *Digera arvensis, Commelina benghalensis, Trianthema portulacastrum, Amaranthus viridis* among the broad-leaf weeds and *Cyperus rotundus* in sedges.

Weeds

Weed population and dry-matter accumulation of weeds significantly varied due to weed-control treatments druing both the years (Table 1). Pooled analysis of the data revealed that maximum weed population and dry-matter accumulation were found to be significant ($P<0.05$) in weedy check. Among the herbicidal weed-control treatments, post-emergence application of propaquizalofop @ 0.0625 and 0.075 kg a.i./ha (T_9) was effective in controlling the weeds, but it also had phytotoxic effects on the crop resulting in stunted growth and lower fodder yields. Weed population and dry matter was found to be 11.2/m² and 0.67q/ha, respectively, in the T_9 treatment. Application of atrazine @ 0.375 + pendimethalin @ 0.75 kg a.i./ha as pre-emergence spray resulted in significantly lower weed population and weed dry matter among the remaining herbicide treatments. Application of atrazine and pendimethalin alone was not effective in controlling the entire weed flora. Grichar *et al.* (2005), Vijayakumar *et al.* (2014) and Galon *et al.* (2016) also observed reduced density of weeds with application of atrazine and pendimethalin or alachlor in combination.

Hand weeding at 20 and 30 DAS exhibited the maximum weed-control efficiency, followed by post-emergence application of propaquizalofop @ 0.075 kg a.i./ha (95.0%), propaquizalofop @ 0.0625 kg a.i./ha and pre-emergence application of atrazine @ 0.375 + pendimethalin @ 0.75 kg a.i./ha (Table 1).

Crop

Growth and fodder yield: Pooled data of 2 years revealed that the maximum plant height and tillers/m row length were recorded with pre-emergence application of atrazine @ 0.375 + pendimethalin @ 0.75 kg a.i./ha which were statistically at par with hand-weeding at 20 and 30 DAS and atrazine @ 0.25 + pendimethalin @ 0.75 kg a.i./ ha, whereas it was significantly higher than all the other treatments. Plant height and tillers/m row length were minimum in case of weedy check (Table 1). Our results confirm the findings of Ishaya *et al* (2007). Different herbicidal treatments did not have any influence on the leaf: stem ratio sorghum fodder.

Maximum green fodder yield under hand-weeded (20 and 30 DAS) plots was found at par with pre-emergence application of atrazine @ 0.375 and pendimethalin @ 0.75 kg a.i./ha and significantly higher than all the other treatments (Table 2). This might be due the fact that the suppressive effect of the herbicides on weeds prevented any weed interference with the crop and hence promoted greater yield throughout the study period (Ishaya *et al*., 2007). The results confirm the findings of Kumar *et al.* (2012). Total dry fodder yield was also maximum when hand weeding was done at 20 and 30 DAS, followed by pre-emergence application of atrazine @ 0.375 + pendimethalin @ 0.75 kg a.i./ha and atrazine @ 0.375 + pendimethalin @ 0.75 kg a.i./ha (Table 2). These 3 treatments were statistically at par with reference to dry fodder yield among themselves and significantly better than rest of the treatments. Application of propaquizalofop as post-emergence spray resulted in the lowest green- and dry-fodder yield of sorghum because of the phytotoxic effect of herbicide on the crop. Weedy check also recorded significantly lower green and dry-fodder yield of sorghum than the rest of the weed-management options. Uncontrolled weedy check caused 28.1 and 32.7% reduction in green- and dry-fodder yield of sorghum, respectively as compared to hand- weeding done at 20 and 30 DAS. Similar trends in green-and dry-fodder yield were also reported by Kumar *et al*. (2008).

Crude protein content and yield: All the herbicidal

Table 1. Effect of different pre- and post-emergence herbicides on weed population, weed dry-matter, weed-control efficiency and growth of parameters sorghum fodder at the time of the first cutting (pooled data of 2 years)

Treatment	Weed population /m^2	Weed dry matter (kg/ha)	Weed control efficiency (%)	Plant height (cm)	Tillers/m row length	Leaf: stem ratio
T_1, Atrazine @ 0.5 kg/ha PE	8.44 (70.2)	541	57.4	163.5	43.7	0.62
T_2, Pendimethalin @ 0.75 kg/ha PE	7.21 (51.0)	422	66.8	167.7	45.8	0.68
T_3, Atrazine @ 0.25 + Pendimethalin @ 0.75 kg/ha PE	5.40 (28.2)	151	88.0	174.2	49.0	0.69
T_4, Atrazine @ 0.375 + Pendimethalin @ 0.75 kg/ha PE	3.94 (14.6)	85	93.3	178.3	53.6	0.68
T_5, Pinoxaden @ 0.0375 kg/ha post-emergence	6.80 (45.3)	249	79.9	125.7	30.5	0.68
T_6, Pinoxaden @ 0.05 kg/ha post-emergence	5.77 (32.3)	177	85.8	117.6	25.3	0.68
T_7, Oxyflourfen @ 0.088 kg/ha PE	5.86 (33.4)	187	85.1	153.8	40.6	0.65
T_8, Oxyflourfen @ 0.146 kg/ha PE	5.12 (25.3)	151	88.0	165.4	44.3	0.62
T_9, Propaquizalofop @ 0.0625 kg/ha Post-emergence	3.49 (11.2)	67	94.7	109.4	22.5	0.74
T_{10}, Propaquizalofop @ 0.0750 kg/ha Post-emergence	3.30 (9.9)	64	95.0	106.0	22.7	0.72
T_{11}, Hand-weeding	2.93 (7.6)	60	95.3	177.2	52.6	0.73
T_{12}, Weedy check	14.56 (211.0)	1274	–	131.7	39.3	0.59
SEm±	0.32	26	–	7.32	2.25	–
CD (P=0.05)	0.94	76	–	21.4	6.56	–

Figures in the parentheses are the original values and outside ones are square root ($\sqrt{x+1}$) transformed values

PE, Pre-emergence

treatments recorded significantly higher crude protein content than the weedy check (Table 2). The maximum average crude protein (7.93%) content was recorded in case of hand weeding at 20 and 30 DAS, followed by pre-emergence application of atrazine @ 0.375 + pendimethalin @ 0.75 kg a.i./ha. Rao *et al*. (2007) also reported that in addition to herbicidal combinations, cultural practices either by hoeing or peg tooth-weeder increased the crude protein content significantly of the sorghum crop mainly owing to higher dry-fodder yield and increased N uptake. The crude protein yield (total of 3 cuts) was maximum (1.45 t/ha) in case of hand-weeding done at 20 and 30 DAS, being was statistically at par with atrazine @ 0.375 + pendimethalin @ 0.75 kg a.i./ha (1.40 t/ha). Propaquizalofop (0.0625 and 0.0750 kg a.i./ha) applied as post-emergence recorded the lowest crude protein yields (0.59 and 0.60 t/ha respectively) owing to low dry-matter yield because of phytotoxic effect of herbicide on the crop. Uncontrolled growth of weeds in weedy check plots resulted in 37.0 and 35.0% reduction in crude protein yield from hand weeding and application of atrazine and pendimethalin (0.375 and 0.75 kg a.i./ha), respectively. Therefore, weeds not only cause reduction in fodder yield but also deteriorate the quality of the fodder crop.

Foliar diseases

The leaf-spot severity of grey leaf spot (*Cercospora sorghi* Ellis & Everh.) was less in plots sprayed with propaquizalofop @ 0.075 kg a.i./ha and 0.0625 kg a.i./ha, followed post-emergence by atrazine @ 0.375 + pendimethalin @ 0.75 kg a.i./ha pre-emergence with moderate grey leaf severity of than the check (Table 2). Both the treatments (propaquizalofop @ 0.075 kg a.i./ha, post-emergence and atrazine @ 0.375 + pendimethalin @ 0.75 kg a.i./ha pre-emergence) were statistically at par with each other during both the years. Similarly, the per cent zonate leaf spot (*Gloeocercospora sorghi* D.C. Bain & Edgerton) was lower in plots treated with weedicides (atrazine @ 0.375 + pendimethalin @ 0.75 kg a.i./ha PE) as compared to check. The correlation between weed population and leaf-spot severity (Fig. 1) showed a significant positive relation (r = + 0.88). It could, thus, be con-

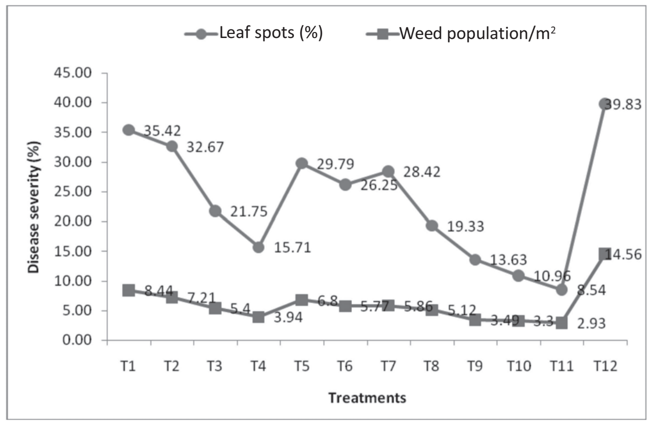

Fig. 1. Relationship between weed population and leaf-spot severity with reference to weedicides (Details of treatments are given in Table 1)

Table 2. Effect of different pre- and post-emergence herbicides on green-fodder, dry-fodder yield (total of 3 cuts), quality and economics of sorghum fodder (pooled data of 2 years)

Treatment	Green-fodder yield (t/ha)	Dry-fodder yield (t/ha)	Crude protein (mean of 3 cuts) (%)	Crude protein yield (total of 3 cuts) (t/ha)	Economics (mean of 2 years)			Grey leaf spot severity (%)	Zonate leaf spot severity (%)
					Cost of cultivation (× 10^3 /ha)	Net returns (× 10^3 /ha)	Benefit: cost ratio		
T_1, Atrazine @ 0.5 kg/ha PE*	77.0	15.2	7.56	1.15	25.00	28.87	1.15	37.7	33.2
T_2, Pendimethalin @ 0.75 kg/ha PE	77.7	15.6	7.67	1.19	25.70	28.66	1.11	34.3	31.0
T_3, Atrazine @ 0.25 + Pendimethalin @ 0.75 kg/ha PE	85.2	17.0	7.78	1.32	25.85	33.79	1.31	23.2	20.3
T_4, Atrazine @ 0.375 + Pendimethalin @ 0.75 kg/ha PE	91.0	17.9	7.87	1.40	25.90	37.79	1.46	17.7	13.6
T_5, Pinoxaden @ 0.0375 kg/ha POE#	62.1	11.9	7.82	0.93	25.95	17.54	0.68	31.3	28.3
T_6, Pinoxaden @ 0.05 kg/ha POE	51.1	9.83	7.83	0.77	26.30	9.44	0.36	28.0	24.5
T_7, Oxyflourfen @ 0.088 kg/ha PE	64.2	12.7	7.80	0.99	26.20	18.71	0.71	30.2	26.7
T_8, Oxyflourfen @ 0.146 kg/ha PE	63.5	12.6	7.81	0.98	26.38	18.08	0.69	22.4	16.3
T_9, Propaquizalofop @ 0.0625 kg/ha POE	37.4	7.6	7.84	0.59	25.45	0.75	0.03	16.6	10.7
T_{10}, Propaquizalofop @ 0.0750 kg/ha POE	38.1	7.5	7.87	0.60	25.55	1.15	0.04	12.9	9.0
T_{11}, Hand weeding	92.5	18.4	7.93	1.45	28.45	36.32	1.28	11.4	5.7
T_{12}, Weedy check	66.6	12.4	7.39	0.91	24.70	21.89	0.89	42.3	37.4
SEm±	2.14	4.66	0.04	0.04	–	–	–	1.3	0.7
CD (P=0.05)	6.26	1.34	0.12	0.12	–	–	–	3.7	1.9

*PE, Pre-emergence; POE, post-emergence

cluded that higher density of weed flora provided suitable microclimate and habitat for development of diseases. Moreover, these leaf spots first appear on grassy weeds infesting the fields and its bunds and later the pathogen population of these leaf spots shifts to the sorghum crop. Samuel *et al*. (2008) surveyed a total of 261 faba bean fields in 12 districts against *Botrytis* grey mold and reported positive correlation of disease incidence (r = + 0.57) and severity (r = + 0.52) with weed density.

Economics

Pre-emergence application of atrazine and pendimethalin (0.375 and 0.75 kg a.i./ha) recorded highest net returns, followed by hand-weeding (Table 2). The benefit: cost ratio was also highest when atrazine and pendimethalin (0.375 and 0.75 kg a.i./ha) were sprayed in combination, followed by atrazine + pendimethalin @ 0.25 + 0.75 kg a.i./ha and hand-weeding. Hand-weeding treatment registered lower benefit: cost ratio due to high cost involved in repeated weedings to keep crop weed-free despite having highest green- and dry-fodder yield, as also reported by Priya and Kubsad (2013).

It can be concluded that pre-emergence application of atrazine + pendimethalin (0.375 + 0.75 kg a.i./ha, respectively) appeared to be the best weed-management practice of all the herbicides tested in reducing weed growth, giving maximum green- and dry-fodder yield and net returns in fodder sorghum. When availability of labour is not a constraint, hand-weeding at 20 and 30 days after sowing can also be a viable option for getting higher productivity of forage sorghum.

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