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Article

Herbicidal Potential of Sorghum and Brassica Against the Weeds of Cotton

Potencial Herbicida do Sorgo e das Brássicas contra Plantas Daninhas do Algodoeiro

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ABSTRACT - Weed infestation is among the main factors which decrease cotton yield. Allelopathy has been well-documented as a phenomenon offering natural weed control in agro-ecosystems. An experiment was conducted to figure out the herbicidal potential of a mixture of sorghum and brassica water extracts (SBWE) against weeds in cotton. Combinations of SBWE each at 16 L ha^{-1} were sprayed alone and in combination in a tank mixed with ⅓ and ¼ doses of both pendimethalin (0.625 and 0.416 kg a.i. ha^{-1}) and S-metolachlor (1.075 and 0.716 kg a.i. ha^{-1}). Recommended doses of pendimethalin (1.25 kg a.i. ha^{-1}) and S-metolachlor (2.15 kg a.i. ha^{-1}) were also sprayed for comparison. As control, a weedy check treatment where nothing was sprayed was also included in the experiment. Lower doses (⅓) of both herbicides in combination with SBWE gave approximately the same level of weed reduction and crop improvement as given by the recommended doses of herbicides. Furthermore, economic and marginal analysis showed that maximum net benefits were obtained in using allelopathic water extracts alone and in combination with lower rates of commercial herbicides. Thus, in conclusion, allelopathy can be employed for weed management and yield maximization in modern agriculture.

Keywords: cotton herbicides, sorghum water extract, brassica water extract, weed dynamics.

RESUMO - A infestação de plantas daninhas está entre os principais fatores que diminuem a produção de algodão. A alelopatia tem sido bem documentada como um fenômeno que oferece controle natural de plantas daninhas nos agroecossistemas. Foi realizado um experimento para descobrir o potencial herbicida de uma mistura de extratos aquosos de sorgo e brássicas (EASB) contra plantas daninhas no algodoeiro. Combinações de EASB, cada um com 16 L ha^{-1}, foram pulverizadas isoladas e em combinação em um tanque misturado com ⅓ e ¼ de doses de pendimethalin (0,625 e 0,416 kg i.a. ha^{-1}) e S-metolachlor (1,075 e 0,716 kg i.a. ha^{-1}). Doses recomendadas de pendimethalin (1,25 kg i.a. ha^{-1}) e S-metolachlor (2,15 kg i.a. ha^{-1}) também foram pulverizadas para fins de comparação. Como controle, também foi incluído no experimento um tratamento sem capina, onde nenhum herbicida foi pulverizado. Em combinação com os EASBs, as doses mais baixas (⅓) de ambos os herbicidas obtiveram, aproximadamente, o mesmo nível de redução de plantas daninhas e melhoramento das culturas, conforme determinado pelas doses recomendadas dos herbicidas. Além disso, uma análise econômica e marginal mostrou que foram obtidos máximos benefícios líquidos com o uso de extratos aquosos alelopáticos isoladamente e em combinação com

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doses menores dos herbicidas comerciais. Assim, em conclusão, a alelopatia pode ser empregada para o manejo de plantas daninhas e maximização da produtividade na agricultura moderna.

Palavras-chave: herbicidas de algodoeiro, extrato aquoso de sorgo, extrato aquoso de brássicas, dinâmica das plantas daninhas.

INTRODUCTION

Weeds are a serious jeopardy which impairs improvement in crop yields. Cotton crop is also severely infested by weeds and hence cotton yield is estimated to decrease by 62-85% (Dogan et al., 2014) depending on the degree of severity. Competition between weeds and cotton plants for nutrients, water and light reduces cotton growth and yield (Bukun, 2004), and contaminates cotton quality because of harboring insects/pests and diseases (Anderson, 1983). Moreover, a significant reduction in cotton growth is also reported as a result of adverse allelopathic effects of weeds (Jabran, 2016). In Pakistan, over the last two decades, use of pesticides has increased 70 times by 80% only in cotton crops, which resulted in increased production costs (Khooharo et al., 2008). Herbicide use is gaining momentum because of the quick action against the increasing diversity of weeds (Ali et al., 2013). However, overexploitation of these herbicides is creating a great deal of issues, e.g., groundwater pollution, death of soil micro fauna (Vickerman, 1988) and other health-related problems (Stewart et al., 2001). Improper use of herbicides has also enhanced resistance in dominating weeds and threats to soil and human health. Ultimately, the search for some eco-friendly techniques is required for weed control in order to sustain the environment (Shahzad et al., 2016). Bio-herbicides are good options to deal with weeds (Boyetchko and Peng, 2004) but they cannot offer the desired level of control against problematic weeds (Charudattan, 2005). Furthermore, they cannot fully replace herbicides (Singh et al., 2006). Thus, there must be an alternative approach to provide optimum level of weed control. Water extracts (WE) of different crops have been exploited for weed control (Cheema et al., 2009), but similarly to bio-herbicides, these cannot provide the desired level of weed control. The combination of bio-herbicides with synthetic herbicides is synergistic (Christy et al., 1993) and has resulted in better weed control in many field crops (Hoagland, 2000). Allelopathic plant extracts either alone or in combination with each other (sorghum, brassica) have been exploited in many studies for efficient weed control (Jamil et al., 2009; Jabran et al., 2010; Farooq et al., 2017). However, to get better weed control as given by the standard herbicides, lower doses of herbicides can be tested with allelopathic SBWE. Allelopathic crops such as sorghum and brassica contain allelochemicals (Nimbal et al., 1996; Turk and Tawaha, 2003) which are nature's own herbicides (Jabran, 2017), are water soluble, have short half-life and are considered to be environmentally safe (Duke et al., 2002). The synergistic action of SBWE with a non-selective herbicide (glyphosate) has been previously studied against weeds of cotton, and weed mortality rate was as equal as given by the recommended herbicide rate (Iqbal et al., 2009). Based on the given synergistic action of allelopathic WE and synthetic herbicides, it was hypothesized in the present study that allelopathic SBWE can be tested with the selective herbicides also. Thus, two selective herbicides (pendimethalin and S-metolachlor) with lower rates were tested in combination with SBWE in a field experiment to check whether total reliance upon synthetic herbicides can be minimized and concerns about environment, health and weed resistance can also be addressed through the use of allelopathy.

MATERIAL AND METHODS

The present experiment was carried out at Adaptive Research Farm, Vehari (30.03 ^{o}N and 72.35 ^{o}E with 135 m altitude). Before sowing, a soil sample was taken from a depth of 0-15 cm with soil auger and analyzed for various physico-chemical properties: pH (8.55), TSS (0.20%), organic matter (0.75%), nitrogen (0.41%), available P_2O_5 (6.6 ppm) and available K_2O (122 ppm). The cotton variety CIM-496 was used as the test crop. It was planted on a well-pulverized seedbed in rows set 75 cm apart with a hand drill. A recommended seed rate of 20 kg ha^{-1} was used for sowing. Thinning was performed after seedling establishment to maintain a 30 cm distance among plants.

Crop husbandry

At the time of sowing, nitrogen (N) and phosphorus (P) at 170 kg ha^{-1} and 60 kg ha^{-1}, respectively, were applied in the field. Urea for N and single super phosphate (SSP) for P were used as a source, and full dose of P and ⅓ N was applied at sowing, while the remaining ⅔ N was divided into two even splits which were top dressed at first irrigation and flowering. All other agronomic practices were kept as per recommendations for this area.

Preparation of water extract and their application

Mature crop herbage of brassica and sorghum was dried under shade and sliced into pieces (2 cm) with a fodder cutter. The chopped material was dipped in distilled water in a tub in a 1: 10 (w/v) ratio for 24 hours. Water extracts (WE) were collected after passing the whole material through sieves (10 and 80 mesh). The filtrate was heated at 100 °C to reduce the volume by 20 times (Cheema and Khaliq, 2000). The resulting concentrated extract was stored at room temperature. Combinations of SBWE (each at 16 L ha^{-1}) were mixed with one third and one fourth doses of both pendimethalin (0.625 and 0.416 kg a.i. ha^{-1}) and S-metolachlor (1.075 and 0.716 kg a.i ha^{-1}). Different treatments include: control (Weedy check), SBWE (each at 16 L ha^{-1}), pendimethalin (1.25 a.i. ha^{-1}), SBWE + pendimethalin (each at 16 L ha^{-1} + 0.625 kg a.i. ha^{-1}), SBWE + pendimethalin (each at 16 L ha^{-1} + 0.416 kg a.i. ha^{-1}), S-metolachlor (2.15 a.i. ha^{-1}), SBWE + S-metolachlor (each at 16 L ha^{-1} + 1.075 kg a.i. ha^{-1}) and SBWE + S-metolachlor (each at 16 L ha^{-1} + 0.716 kg a.i. ha^{-1}). All the herbicides and WE combinations were sprayed as direct post-emergence at 22 days after sowing (DAS). Spray volume was adjusted to 300 L ha^{-1} and the treatments were applied with the help of a Knapsack hand sprayer fitted with a flat fan nozzle.

Weed parameters

A 50 cm x 50 cm quadrate was placed at two places in the respective plots and then the average was taken to record total weed density. Weeds were cut from the bottom level and brought to the laboratory to record biomass. For weed dry weight, the sampled weeds were dried in a hot air oven at 70 °C to constant weight, which was measured with the help of an electrical balance. The same procedure was repeated at 50 and 70 DAS.

Crop parameters

Crop data were recorded for different growth and yield related traits, e.g., plant height (cm), monopodial and sympodial branches per plant, bolls per plant, weight per boll (g) and seed cotton yield (kg ha^{-1}) following Shah et al. (2017).

Statistical Analysis

Each treatment was applied to 6 m x 4.5 m plots and different treatments were arranged according to a randomized complete block design and repeated thrice. Fisher's analysis of variance was used to analyze the data and, for comparison of treatments, the least significance difference test (LSD test) was applied at 5% (Steel et al., 1997).

RESULTS AND DISCUSSION

The experimental area was affected with a wide range of weeds belonging to both broad and narrow leaf families. Among major weeds; horse purslane, purple nutsedge, jungle rice, field bind weed, garden spurge, and puncture clover were the most dominating in the experimental plots. All the treatments showed a significant reduction in dry weight for all weeds (Table 1). In comparison to the weedy check plots, there was maximum reduction of 79% (mean of 50 DAS and 75 DAS) in dry weight for all weeds where the label dose of S-metolachlor (2.15 kg a.i. ha^{-1}) was applied (Table 1) while the label dose of pendimethalin (1.25 kg a.i. ha^{-1}) reduced dry weight by 71%. In comparison, the combination of allelopathic SBWE with reduced doses of S-metolachlor

Table 1 **-** Efficacy of Sorghum water extract (sorgaab) and Brassica water extract (BWE) on total weed density and total weed biomass

Treatment	Rate	Total Weed Density (0.25 m^2)			Total Weed Biomass (g. 0.25 m^{-2})		
		50 DAS	75 DAS	Mean	50 DAS	75 DAS	Mean
Control (Weedy check)		106.2 a	135.3 a	-	74.27 a	112.3 a	-
Sorgaab + BWE	each at 16 L ha^{-1}	34.83 cd (-67.20)	51.33 d (-62.14)	-66	24.76 cd (-66.83)	38.25 c (-65.90)	-66
Pendimethalin	1.25 kg a.i. ha^{-1}	28.83 ef (-72.85)	42.67 e (-68.54)	-73	21.65 d (-71.83)	33.14 d (-70.45)	-71
Sorgaab + BWE + pendimethalin	each at 16 L ha^{-1} + 0.625 kg a.i. ha^{-1}	32.17 de (-69.70)	51.67 d (-61.88)	-66	25.01 cd (-66.55)	39.26 c (-65)	-66
Sorgaab + BWE + pendimethalin	each at 16 L ha^{-1} + 0.416 kg a.i. ha^{-1}	41.00 b (-61.28)	61.83 b (-54.36)	-59	29.77 b (-60.07)	52.38 b (-53.33)	-57
S-metolachlor	2.15 kg a.i ha^{-1}	25.67 f (-75.82)	36.50 f (-73.11)	-79	17.83 e (-76.19)	30.84 d (-81.46)	-79
Sorgaab + BWE + S-metolachlor	each at 16 L ha^{-1} + 1.075 kg a.i. ha^{-1}	29.83 e (-71.91)	48.83 d (-63.99)	-74	23.18 cd (-68.97)	37.56 c (-66.52)	-68
Sorgaab + BWE + S-metolachlor	each at 16 L ha^{-1} + 0.716 kg a.i. ha^{-1}	36.17 c (-65.94)	55.50 c (-59.09)	-68	25.29 c (-66.12)	48.50 b (-56.78)	-61
LSD value at $P \leq 0.05$		3.5	3.23		3.34	4.06	

DAS: Days after sowing; Sorgaab: sorghum water extract; BWE: Brassica water extract. Figures sharing the same letter do not differ statistically at $p \leq 0.05$ by the LSD test. Figures given in parenthesis show % decrease or increase over control.

at 1.075 kg a.i. ha^{-1} (⅓rd of the recommended dose) and S-metolachlor at 0.716 kg a.i. ha^{-1} (¼th of recommended dose) reduced dry weight for all weeds by 68% and 61%, respectively (Table 1). However, the combination of allelopathic SBWE with reduced doses of pendimethalin at 0.625 kg a.i. ha^{-1} (⅓ of the recommended dose) and pendimethalin at 0.416 kg a.i. ha^{-1} (¼ of the recommended dose) reduced dry weight for all weeds by 66% and 57%, respectively (Table 1). The reduction in weed biomass after application of the SBWE dose alone was 66%, which was good enough.

Seed cotton yield, number of bolls, average boll weight, sympodial and monopodial branches were significantly influenced by all combinations of crop WE with lower doses of herbicides (Table 2). Maximum seed cotton yield (2,387 kg ha^{-1}) was recorded in plots where the recommended dose of S-metolachlor (2.15 a.i. ha^{-1}) was applied and statistically similar yield (2,300 kg ha^{-1}) was found where SBWE were sprayed in tank mixed with a lower rate of S-metolachlor at 1,075 kg a.i. ha^{-1} (⅓ of the recommended dose) and the label dose of pendimethalin 1.25 kg a.i. ha^{-1} (2,331 kg ha^{-1}) (Table 2). This yield pattern was followed by the treatment of SBWE application each at 16 L ha^{-1} (2,239 kg ha^{-1}). Other combinations of SBWE with lower rates of pendimethalin at 0.625 kg a.i. ha^{-1} (⅓ of the recommended dose) and further with S-metolachlor and pendimethalin at 0.716 kg a.i. ha^{-1} and 0.416 kg a.i. ha^{-1} (¼ of the recommended dose) also gave good seed cotton yield which was comparable to that of weedy check plots (Table 2). An almost similar trend of improvement was found for all other yield contributing parameters, e.g., number of bolls, average boll weight, sympodial and monopodial branches of cotton (Table 2).

Table 2 **-** Efficacy of sorghum water extract (sorgaab) and brassica water extract (BWE) on yield and yield related traits of cotton

Treatment	Rate	Monopodial branches per plant	Sympodialbranches per plant	No. of bolls per plant	Average ball weight (g)	Seed cotton yield (kg ha^{-1})
Control (Weedy check)	-	1.47 c	9.2 c	6.47 e	2.34 d	1621 e
Sorgaab + BWE	Each at 16 L ha^{-1}	2.40 ab	15.00 b	17.33 bc	3.57 a	2239 bc
Pendimethalin	1.25 kg a.i. ha^{-1}	2.00 abc	15.37 b	19.87 ab	3.59 a	2331 ab
Sorgaab + BWE + pendimethalin	each at 16 L ha^{-1} + 0.625 kg a.i. ha^{-1}	1.60 c	14.87 b	16.00 c	3.33 bc	2170 c
Sorgaab + BWE + pendimethalin	each at 16 L ha^{-1} + 0.416 kg a.i. ha^{-1}	1.47 c	12.40 bc	12.00 d	3.11 c	1906 d
S-metolachlor	2.15 kg a.i. ha^{-1}	2.47 a	19.93 a	22.87 a	3.67 a	2387 a
Sorgaab + BWE + S-metolachlor	each at 16 L ha^{-1} + 1.075 kg a.i. ha^{-1}	2.33 ab	15.73 b	17.40 bc	3.49 ab	2300 ab
Sorgaab + BWE + S-metolachlor	each at 16 L ha^{-1} + 0.716 kg a.i. ha^{-1}	1.87 bc	12.27 bc	14.43 cd	3.31 bc	2014 d
LSD value at $P \leq 0.05$		0.55	4.12	3.49	0.22	118.7

Sorgaab: sorghum water extract; BWE: Brassica water extract. Figures sharing the same letter do not differ statistically at $p \leq 0.05$ by the LSD test.

The economic feasibility of all weed management strategies were evaluated by performing economic and marginal analysis, which provided information on net and marginal returns and dominance of every individual treatment. All treatments gave higher net benefits as compared to the control treatment (Table 3). Although maximum net benefits were obtained where the recommended rates of S-metolachlor (2.15 kg a.i. ha^{-1}) and pendimethalin (1.25 kg a.i. ha^{-1}) were applied, very similar net benefits gained where SBWE was tank mixed with ⅓ of the recommended dose of S-metolachlor. In case of marginal analysis, treatment combination where SBWE was tank mixed with ⅓ of the recommended dose of S-metolachlor was found to be the best with maximum marginal rate of return (MRR) (104.25%) in comparison to all other treatments (Table 4). This was followed by MRR obtained from applications of SBWE each at 16 L ha^{-1} (62.43%) and the recommended dose of S-metolachlor at 2.15 kg a.i. ha^{-1} (17.81%) while all other treatments proved to be uneconomical at prevailing prices as a result of lower benefits and higher variable cost (Table 4).

Table 3 - Economic Analysis of different treatments

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	Remark
Seed cotton yield	1621	2239	2331	2170	1906	2387	2300	2014	(kg ha^{-1})
Adjusted yield	1458.9	2015.1	2097.9	1953	1715.4	2148.3	2070	1812.6	To bring at farmer's (10% less)
Gross income	94828.5	130981.5	136363.5	126945	111501	139639.5	134550	117819	*Rs. 2600/40kg
Cost of herbicide	0	0	1420	710	473	1385	692	462	market price of herbicides
Cost of sorgaab and BWE	0	150	150	150	150	150	150	150	Expenditure on preparation of 16L sorgaab & BWE
Sprayer application cost	0	360	360	360	360	360	360	360	Rs.300/man (1man/day/ha)
Sprayer rent	0	60	60	60	60	60	60	60	Rs. 60/spray
Variable cost	0	570	1990	1280	1043	1955	1262	1032	
Net benefit	94828.5	130411.5	134373.5	125665	110458	137684.5	133288	116787	Rs. ha^{-1}

* Rs 105.35 = 1 US Dollar. T_1: Control (weedy check); T_2: Sorgaab + brassica water extract (BWE) each at 16 L ha^{-1}; T_3: pendimethalin (Stomp 330 EC) at 1.25 kg a.i. ha^{-1}; T_4: pendimethalin at 0.625 kg a.i. ha^{-1} + sorgaab + BWE each at 16 L ha^{-1}; T_5: pendimethalin at 0.416 kg a.i. ha^{-1} + sorgaab + BWE each at 16 L ha^{-1}; T_6: S-metolachlor (Dual Gold 960 EC) at 2.15 kg a.i. ha^{-1}; T_7: S-metolachlor at 1.075 kg a.i. ha^{-1} + sorgaab + BWE each at 16 L ha^{-1}; T_8: S-metolachlor at 0.716 kg a.i. ha^{-1} + sorgaab + BWE each at 16 L ha^{-1}

Table 4 **-** Marginal Analysis of different treatments

Treatment	Variable cos (*Rs.)	Net profit (Rs.)	Marginal cost	Marginal net benefits	Marginal rate of returns (%)
Control (weedy check)	0	94828.5	-	-	-
Sorgaab + brassica water extract (BWE) each at 16 L ha^{-1}	570	130411.5	570	35583.0	62.43
S-metolachlor at 0.716 kg a.i. ha^{-1} + sorgaab + BWE each at 16 L ha^{-1}	1032	116787.0	462	D	D
Pendimethalin at 0.416 kg a.i. ha^{-1} + sorgaab + BWE each at 16 L ha^{-1}	1043	110458.0	11	D	D
S-metolachlor at 1.075 kg a.i. ha^{-1} + sorgaab + BWE each at 16 L ha^{-1}	1262	133288.0	219	22830.0	104.25
Pendimethalin at 0.625 kg a.i. ha^{-1} + sorgaab + BWE each at 16 L ha^{-1}	1280	125665.0	18	D	D
S-metolachlor (Dual Gold 960 EC) at 2.15 kg a.i. ha^{-1}	1955	137684.5	675	12019.5	17.81
Pendimethalin (Stomp 330 EC) at 1.25 kg a.i. ha^{-1}	1990	134373.5	35	D	D

* Rs 105.35 = 1 US Dollar. D: Dominant treatment; Rs. Rupees.

Total dry matter accumulated by a plant indicates the extent of nutrient absorption and utilization by that plant, which determines the efficacy of such plant to utilize the available resources. Thus, in this experiment, in plots where there was less weed-crop competition, expression of yield and yield related traits was maximum (Table 2) hence maximum net benefits were obtained (Table 3). In the case of weeds, knowledge of total dry matter offers insights on the ability of weed to compete with main crops. All the dominating weeds of the experimental area were significantly influenced by all WE combinations of allelopathic plants with lower rates of herbicides. These results indicate that the action of SBWE with selective herbicides is synergistic as the same action was previously observed for non-selective herbicides (Iqbal et al., 2009). This phenomenon of killing weeds by the combined use of plant WE in combination with lower rates of synthetic herbicides has been reported previously by many scientists (Kebede, 1994; Streibig et al., 1999; Ihsan et al., 2015). Furthermore, in parallel to our findings, it has also been previously established that herbicide dose can be minimized up to 66% in combination with allelopathic plant WE. (Cheema et al., 2003). Health and other issues associated with use of chemical herbicides, e.g., resistance development in weeds and residual effects in food (Hossain, 2015), alternative methods of using weeds, are gaining momentum and, consequently, integrated weed management in main crops should be developed (Zhang, 2003). Reduced doses of both herbicides in combination with SBWE significantly enhanced yield and yield contributing traits. The increase in seed cotton yield in this study was due to reduced crop-weed competition and the fact that, in the absence of weeds, all the available resources were utilized by the cotton crop (Askew and Wiltcut, 2001). Total weed biomass was better controlled in all treatments where crop WE were tank mixed with low doses of herbicides. This synergistic action has been addressed in many previous studies (Cheema et al., 2000). Furthermore, this increase in yield was positively correlated with different yield contributing parameters such as number of bolls and average boll weight (Boquet et al., 2004), which were also higher in the combination treatments. Good crop yield can be achievable by reducing the herbicide dose up-to 50% (Kirkland et al., 2000). However, for the best results, commercial herbicides can be tank mixed with a combination of WE of allelopathic crops (Afridi and Khan, 2014).

In conclusion, reliance upon synthetic herbicides can be minimized up to 66% and the best economic benefits can also be obtained by using allelopathy of sorghum and brassica. Water extracts of these two crops can be exploited to not only control cotton weeds but also increase seed cotton yield.

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