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Allelopathic potential of Sorghum for weed control in Maize (*Zea mays* L.) in climate change sustainable agriculture

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Allelopathy is a natural phenomenon which has proved helpful in eradicating unwanted flora in the field crops. Many attempts have been made, over the years, to minimize chemical weed control which has come in handy for the purpose. In the current study, various allelopathic treatments were used as sole or combined application with chemical herbicide "atrazine". The results showed that these treatments had a profound inhibiting effect on the fresh and dry weeds weight of *T. portulacastrum*, *C. rotundus* and *E. colona*, wherein 1000-grains weight and grain yield was also enhanced. Among the treatments, sorghum mulch, sorgaab sprays (double and triple), combination of sorghum mulch and sorgaab and that of sorgaab and half dose of atrazine, all performed better than the control, however single spray of sorgaab didn't prove effective. Combination of sorgaab with half dose of atrazine was economically viable treatment as well. Therefore, it was concluded that the herbicide rate can be reduced to half if sorghum water extract is combined with it to control weeds in maize crop.

Keywords: *Maize*, sorghum allelopathy, weed management, yield

INTRODUCTION

Maize (*Zea mays* L.) is Pakistan's most widely farmed cereal crop, trailing just wheat and rice in terms of cultivated area and total production (Ali et al. 2011). The maize grain is a good source of proteins (10.4 percent), lipids (4.5 percent), and carbohydrates (71.8 percent) and contains minerals like calcium, phosphorus, and sulphur (Farhad et al. 2009). Maize was cultivated on 1413 thousand hectares area in Pakistan, giving 7236 thousand tons with an average yield of 5.12 t ha-1 (Anonymous, 2019).

Despite its high yielding potential, maize yields are still very low in comparison to advanced countries around the world. Despite the development and release of several high-yielding varieties, the required potential yield could not be achieved. This is primarily owing to farmers' weed management practices receiving little or no attention (Khaliq et al. 2004). Weeds and crop plants compete fiercely for carbon dioxide, nutrients, temperature, light, space and moisture, among other things, which can result in severe yield deficits in profitable crops in some circumstances (Amare, 2014). Allelopathy is now being proposed for weed management, particularly since that the widespread use of herbicides in contemporary agriculture has raised worries about herbicide residues in the environment and the rapid development of herbicide resistance by weeds (Ayeni and Kayode, 2011). Over 295 weed biotypes have developed resistance to major pesticides, according to research. As a result, non-herbicidal innovation, such as improving crop allelopathic ability, is becoming more important in weed management (Wu et al. 1999). Allelochemicals are biosynthesized herbicides that are easily biodegradable and thought to be safer than herbicides (Ayeni and Kayode, 2011).

It's a well-known fact that sorghum plants contain allelochemicals, which can impede plants, particularly weeds. Many researches have discovered that a mature sorghum plant has a large number of allelochemicals that can be phytotoxic to many nearby plants. Cheema and Khaliq (Cheema and Khaliq, 2000). The application of allelopathic residues of sorghum in the form of surface mulches and water extracts as foliar sprays has shown encouraging effects in modern weed management techniques, according to (Mehmood et al. 2010).

Sorghum water extracts, also known as sorgaab (Afzal et al. 2014), and sorghum mulch (Cheema and Khaliq, 2000), may have a significant impact on weed development and may be advantageous in increasing crop yields.

Keeping in view the undeniable importance of allelopathic properties possessed by sorghum, as vividly demonstrated in the previous literature, this study was planned with these objectives;

1) To assess the efficacy of sorghum mulch and sorghum water extract (sorgaab) for weed control in summer maize.

2) To examine the best combination of sorghum extracts, sorghum mulch and reduced doses of atrazine.

MATERIALS AND METHODS

A study was undertaken at the research farm of Agronomy, Faculty of Agriculture, Gomal University, Dera Ismail Khan, during kharif 2019 to assess the sole and combined applications of sorghum aqueous extract (sorgaab), sorghum mulch, and decreased doses of atrazine for weed control in summer maize (Zea mays L.). The experiment was carried out in a three-replication randomized complete block design (RCBD). The hybrid maize variety "HC-8080" was sowed 60cm apart on ridges with a plant to plant distance of 25cm. The net plot size was fixed at 12m2 (3m x 4m). There were four ridges in each plot. The experiment employed a seed rate of 25 kg ha-1. In the form of Urea, Single super phosphate, and Sulfate of potash, nitrogenous, phosphatic, and potash fertilizers were applied at 120 kg ha-1 (N), 60 kg ha-1 (P), and 60 kg ha-1 (K) respectively. The full amount of P and K fertilizers, as well as half of the N fertilizer, were applied at the time of planting, with the remaining half applied during the second irrigation.

Sorghum plant herbage was gathered at maturity, dried, chaffed with a fodder cutter into 2 cm pieces, and stored under cover to avoid rainwater leaching. To make sorgaab, chaffed sorghum material was soaked in distilled water in a 1:20 (g/ml) ratio for 72 hours at room temperature (Cheema and Khaliq, 2000). The latter was obtained by filtering the mixture (herbage and water) through a screen. The treatments included; T1= Control (weedy check), T2= Sorghum mulch @ 10 t ha-1, T3= Sorgaab @ 20 L ha-1 15 DAS, T4= Sorgaab @ 20 L ha-1 15 & 30 DAS, T5= Sorgaab @ 20 L ha-1 15, 30 & 45 DAS, T6= Sorghum mulch @ 10 t ha-1 + sorgaab @ 20 L ha-1, T7= Sorgaab @ 20 L ha-1 + ½ dose of Atrazine (875 mL a.i. ha-1) and T8= Full dose of Atrazine (1750 mL a.i. ha-1)

Parameters recorded

In order to calculate the fresh biomass before and after treatment, weed species present in an area of 1m-2 were weighed for and then their mean was calculated. Similarly, for dry weed weight before and after treatment, weed plants (m-2) were oven dried at 72 oC for 48 hours and were weighed for dry weed biomass and were then averaged out. Number of grains and thousand grains were counted from each plot and were weighed using an electric balance for obtaining grains per cob and 1000-grains weight. Likewise, grain yield was obtained from each plot separately and the results were converted to ton per hectare. The data of all the parameters were analyzed through analysis of variance technique and means were evaluated via LSD test at 5% probability. Standard procedures were adopted for raising maize and sorghum crops.

RESULTS

Weeds density (m-2) before and after treatments with weed control efficiency

Data presented in table 1 showed non-significant differences among different treatments regarding weeds density (m-2) before treatments. Uniform emergence of weeds were allowed to check the efficiency of different treatments in this regard. After application of treatments, there were found significant differences among the means. Maximum reduction was found in T7 (sorgaab 20 L ha-1 + 1/2 dose of atrazine) followed by full dose of atrazine (chemical weed control). Maximum weeds density was found in control (weedy check) before and after treatments. However, sorgaab application at different time also reduced the frequency of weeds. Sorghum mulch also reduce the number of weeds as compared to control. Maximum weeds control efficiency was registered in T8 (Chemical weed control) followed by T7 (Integrated weeds control). Sorghum mulch also showed better weeds control efficiency.

Table 1: Effect of various allelopathic treatments on fresh weight (g) of weeds

Treatments	Fresh weight (g)	Fresh weight	Fresh weight	Fresh weight	Fresh weight	Fresh weight

	of *T. portulacastrum* before treatment	(g) of *T. portulacastrum* after treatment	(g) of *C. rotundus* before treatment	(g) of *C. rotundus* after treatment	(g) of *E. colona* before treatment	(g) of *E. colona* after treatment
T1	29.76 c	29.55^{NS}	40.01 abc	41.33 a	11.58 d	25.233 a
T2	28.54 c	21.35	29.37 bcd	23.29 bc	14.00 d	19.46 b
T3	32.54 bc	25.88	34.54 bcd	29.40 b	14.11 d	12.87 cd
T4	38.90 abc	30.81	24.45 cd	22.38 bcd	23.47 c	15.32 bc
T5	44.70 abc	23.71	34.48 bcd	19.57 cd	30.34 bc	10.03 cde
T6	31.84 bc	11.34	22.13 d	22.34 bcd	10.77 d	12.91 cd
T7	52.23 ab	22.72	43.41 ab	15.40 d	32.52 b	9.69 de
T8	58.08 a	31.90	50.50 a	19.26 cd	51.91 a	6.60 e
$LSD_{0.05}$	**21.20**	----	**15.61**	**7.17**	**8.23**	**5.50**

The non-similar letter(s) in a specific column present significance of the mean values at 5% probability level

Fresh weeds weight (g) before and after treatment

During the current study, weed species present in maize field were subjected to various allelopathic treatments of sorghum along with half dose of atrazine herbicide. The data contained in Table 1 elucidated that the entire set of treatments positively influenced the fresh weight of weeds except Trianthema portulacastrum which showed resistance against all the treatments including the chemical herbicide. Among the different weed control treatments, integration of sorgaab and half dose of chemical herbicide was found effective in maximally reducing the fresh weight (15.40 g) of C. rotundus in comparison with check (41.33 g). This treatment even showed better results than full dose of atrazine (19.26 g) in case of C. rotundus. Three sprays of Sorgaab @ 20 L ha-1 also proved as a better inhibitor for fresh weed weight (19.57 g) as it was statistically at par with full dose of herbicide. Similarly, two sprays of sorgaab and combination of sorgaab with sorghum mulch reduced the aforementioned parameter by 22.38 g and 22.34 g respectively. Sorghum mulch and one sorgaab spray were next in line (23.29 g & 29.40 g) regarding the attribute under study. On the other hand, atrazine (100%) showed maximum reduction in fresh weight (6.60 g) of E. colona which was followed by integrated dose of sorgaab and atrazine (50%) (9.69 g). Fresh weight of E. colona was found to be inhibited by three sprays of sorgaab (10.03 g), whereas sorgaab single spray plus combination of sorgaab & mulch gave statistically similar weights i.e. 12.87 g & 12.91 g, in the presented order. Sorghum mulch did reduce the fresh weight (19.46 g) as compared to control (25.23 g) but was not found as effective as the other treatments under observation.

Dry weeds weight (g) before and after treatment

The allelopathic treatments, either applied sole or in combination with the herbicide, substantially reduced the dry weight of weeds under observation (Table-3). It was witnessed that 100% dose of atrazine maximally reduced the dry weight (4.30 g) of T. portulacastrum as compared to control (14.69 g). Combination of sorghum mulch and sorgaab came out to be the best performing treatment after recommended dose of atrazine (100%), as it reduced the dry weight by 8.36 g. Similarly, sorghum mulch, sorgaab single, double and triple spray, and sorgaab + atrazine (50%) reduced the dry weight of T. portulacastrum by 9.33 g, 9.05 g, 9.02 g, 9.74 g and 9.57 g, respectively turning out to be statistically similar with each other. Likewise, atrazine (100%), sorgaab with atrazine (50%) and sorgaab with sorghum mulch affected dry weight (8.88 g, 10.18 g and 8.65 g, respectively) of C. rotundus the most. It was further deduced that sorghum mulch, double and triple sorgaab spray performed statistically at par in reducing the dry weight (12.70 g, 11.80 g and 11.76 g), in the respective order. Nevertheless, single sorgaab spray (22.34 g) could not perform better than the control treatment (18.03 g). In case of E. colona, sorghum mulch (10.50 g), sorgaab double (13.48 g) and triple spray (8.62 g), sorghum mulch + sorgaab (5.31 g), sorgaab + atrazine (50%) (5.97 g) and atrazine (100%) (9.73 g) succeeded in curtailing the dry weight. However, sorgaab single spray gave statistically similar results (15.16 g) as that of the control (24.91 g).

Number of grains cob-1, 1000-grains weight (g), grain yield (t ha-1) and harvest index of maize

Table-3 elucidated the data regarding grains cob-1, 1000-grains weight and grain yield. It was clear from the data that grains per cob were significantly affected due to sorghum allelopathy , however, full dose of atrazine produced maximum grains (292.57) which was statistically similar with those of sorghum mulch (262.70), two and three sorgaab sprays (273.98 & 279.17), sorgaab + sorghum mulch (266.86) and sorgaab + half dose of herbicide (285.62). Single spray (262.70) performed better than the control (218.40), nevertheless, it was the least affective treatment among others. Recommended dose of atrazine and combination of sorgaab and atrazine @ 50% produced heavier grains (205.62 g and 197.59 g, respectively) and higher grain yield (6.92 t ha-1 and 6.45 t ha-1).

Table 2: Effect of various allelopathic treatments on dry weight (g) of weeds

Treatments	Dry weight (g) of *T. portulacastrum* before treatment	Dry weight (g) of *T. portulacastrum* after treatment	Dry weight (g) of *C. rotundus* before treatment	Dry weight (g) of *C. rotundus* after treatment	Dry weight (g) of *E. colona* before treatment	Dry weight (g) of *E. colona* after treatment
T1	10.03 cde	14.69 a	19.67	18.03 ab	24.17	24.91 a
T2	9.69 de	9.33 b	14.45	12.70 bc	15.13	10.50 b
T3	12.87 cd	9.05 b	19.90	22.34 a	17.69	15.16 ab
T4	12.91 cd	9.02 b	16.43	11.80 bc	23.27	13.48 b
T5	15.32 bc	9.74 b	22.34	11.76 bc	19.12	8.62 b
T6	6.60 e	8.36 bc	18.87	8.65 c	8.96	5.31 b
T7	19.46 b	9.57 b	16.26	10.18 c	17.03	5.97 b
T8	25.23 a	4.30 c	19.80	8.88 c	25.89	9.73 b
$LSD_{0.05}$	**5.50**	**4.36**	----	**6.79**	----	**10.50**

The non-similar letter(s) in a specific column present significance of the mean values at 5% probability level

Table 3: Effect of various allelopathic treatments on grains cob-1, 1000-grains weight (g) and grain yield (t ha-1) in hybrid maize

Treatments	Number of grains cob^{-1}	1000-grains weight (g)	Grain Yield (t ha^{-1})
T1	218.40 c	124.95 e	4.17 d
T2	262.70 ab	156.92 cd	5.29 bcd
T3	258.80 b	137.44 de	4.44 d
T4	273.98 ab	164.50 c	4.66 cd
T5	279.17 ab	177.41 bc	5.73 abc
T6	266.86 ab	168.60 c	5.16 bcd
T7	285.62 ab	197.59 ab	6.45 ab
T8	292.57 a	205.62 a	6.92 a
$LSD_{0.05}$	**32.17**	**22.51**	**1.27**

The non-similar letter(s) in a specific column present significance of the mean values at 5% probability level

Moreover, sorgaab triple spray, sorgaab + sorghum mulch, sorgaab double spray, sorghum mulch, and sorgaab single spray were next to the aforementioned treatments which had more 1000-grain weight i.e. 177.41 g, 156.92 g, 168.60 g, 164.50 g, and 137.44 g. The control treatment on the other hand produce light weighted seed of 124.95 g. Furthermore, sorgaab triple spray, sorghum mulch, sorgaab + sorghum mulch and sorgaab double spray gave higher grain yield of 5.73, 5.29, 5.16 and 4.66 t ha-1, in the respective manner. On the contrary, single sorgaab spray remained ineffective in terms of grain yield as it produced 4.44 t ha-1 which was statistically similar to that of the control (4.17 t ha-1). Assessment of harvest index (%) was shown in table 3. Maximum harvest index was registered in T8 (chemical weeds control, as complete dose of atrazine) followed by T2 and T7 respectively. Remaining treatments remained behind these treatment. Integrated weeds control T7 (sorgaab + ½ dose of atrazine) also produced significant harvest index after T8 and T2.

Growth parameters of maize

Allelopathic potential of sorghum (sorgaab) extract to suppress weeds and improve the growth of maize expressed in table 4. Data about plant height of maize (cm), crop growth rate (gm m-2 day-1), SPAD value and biomass of maize at maturity (t ha-1) presented in table 4. Significant variation in plant height were found by application of different treatments. Sorghum water extract (T3) (20 L/ha after 15 DAS) produced taller plants followed by T4 (20 L/ha after 15 and 30 DAS) application and T7 (chemical weeds control). Minimum height was recorded in T1 (control). High crop growth rate was recorded in T7 followed by T6 and T5. Statistically these treatments produced at par results. T1 (control) recorded low crop growth rate as compared to the other treatments. Maximum SPAD value about chlorophyll content determined in T7 followed by T6. Similar pattern of SPAD value occurred as in plant height. A prominent biomass production take place in chemical weed control followed by T6, T5 & T4. Statistically results of these treatments were at par. Trend of biomass production remained same as in crop growth rate of maize.

Table 4: Benefit cost ratio in maize under the influence of allelopathic treatments

Treatments	Grain yield ($t\ ha^{-1}$)	Total variable cost ($PKR\ ha^{-1}$)	Gross income ($PKR\ ha^{-1}$)	Total cost ($PKR\ ha^{-1}$)	Net income ($PKR\ ha^{-1}$)	BCR
T1:Weedy check	4.17	0	166800	90000	76800	0.85 d
T2: SM @ 10 t ha^{-1}	5.29	1000	211600	91000	120600	1.32 b
T3: SWE @ 15 L ha^{-1} (15 DAS)	4.44	300	177600	90300	87300	0.96 d
T4: SWE @ 15 L ha^{-1} (15 & 30 DAS)	4.66	600	186400	90600	95800	1.05 c
T5: SWE @ 15 L ha^{-1} (15, 30 & 45 DAS)	5.73	900	229200	90900	138300	1.52 ab
T6: SM @ 10 t ha^{-1} + SWE @ 15 L ha^{-1}	5.16	1300	206400	91300	115100	1.26 b
T7: SWE @ 15 L ha^{-1} + ½ dose of atrazine	6.45	1500	258000	91500	166500	1.81 ab
T8: Full dose of atrazine	6.92	1200	276800	91200	185600	2.03 a
$LSD_{0.05}$						**0.11**

Variable cost includes the cost of mulch preparation @ Rs.100/ton, SWE @ RS. 200, Spray rent @ Rs. 50, Labor charges @ Rs. 50, Herbicide charges @ Rs. 1200

Benefit Cost Ratio (BCR)

The economic analysis, as can be seen in table given below, depicted that maximum economic returns (2.03) were achieved through the application of recommended atrazine dose. However, better returns (1.81) were also witnessed when sorgaab was mixed with half dose of atrazine. Three sprays of sorgaab also proved to be a promising treatment as it gave 1.52 benefit cost ratio. Similarly, other allelopathic treatments i.e. sorghum mulch (1.32), sorghum mulch + sorgaab (1.26) and two sprays of sorgaab (1.05) gave reasonable economic returns. Single spray of sorgaab could not affect weed growth, thus giving lower benefit cost ratio (0.96). Ali et al. (2011) and Afzal et al. (2014) explained the fruitful effects of allelopathic treatments and reported that sorgaab mixed with half dose of herbicide was better compared to the full herbicide dose which inhibited weeds, produced more grain in maize and ultimately gave higher net returns.

Soil analysis before and after maize crop

Data presented in table 7 elucidated soil analysis before maize crop. While data in table 8 showed soil analysis after the maize crop. Soil of experimental site is alkaline in nature (pH > 8.3), low in organic matter and nitrogen, salinity level is also high (table. 7) showed improvement in soil health (Table 8). Improvement and reduction in pH could be seen in all treatments except T9 (chemical weed control). T6 determined maximum reduction in pH, where sorghum mulch and sorgaab both are used. Sorghum mulch also reduced pH and salinity. T6 also enhanced organic matter and soil nitrogen by reducing salt content of soil. Sorghum not only suppress the weeds but also improve the soil health by decomposing of weeds in the soil.

DISCUSSION

Sorghum allelopathy has played tremendous role in suppressing weed growth and benefiting crop yields over the years. It has been utilized in various ways by a number of researchers with the aim to avoid uneconomical use of weedicides. Although, herbicides prove more affective in weed control than any of the natural sources, however, continual use of such chemicals have by and large deteriorated that physical structure of the soil and have disturbed the life cycle of microbes as well (Khaliq et al. 2010). Many researchers have preferred combined use of allelopathic substances with reduced doses of chemical herbicides to kill weeds. They have reported that sole application of allelopathic sprays are not as effective as that of the herbicide, however, their combination has proved helpful in minimizing the doses of herbicides (Khaliq et al. 2004; Afzal et al. 2014).

In the current study we have applied sorgaab as spray and mulch with atrazine to control different weed species in maize crop. After the analysis, the data showed that all the allelopathic materials suppressed weed growth and helped in increasing the growth and yield of maize except single spray of sorgaab. Combination of sorgaab and 50% dose of atrazine gave promising results as this treatment reduced the fresh weight of C. rotundus and E. colona better than herbicide label dose. The data made it clear that the allelochemicals present in sorgaab and/or sorghum mulch material presented hindrance in the growth of weed species except T. portulacastrum. The latter might have developed resistance by converting the active ingredients of herbicide and allelopathic treatments in to inactive form, thereby averting the harmful effects. Cheema et al. (2005) and Farhad et al. (2009) reported that allelopathic treatments had enough potential to control the weed population. They also showed that allelopathic foliar sprays combined with the herbicide had more promising outcomes in reducing weed population and fresh and dry weight and increment in weeds control efficiency. Chemically and integrated weeds control efficiency are better than other treatments. Similar findings were published by Kadam et al. (2021).

Similarly, Integrated weed control (IWM), sorghum water extract (sorgaab) and sorghum mulch significantly affected the all maize growth parameters. However, chemical weeds control and IWM produced at par results as described by Razzaq et al. (2012) and Zahid et al. (2012). According to them, using of allelopathic crops extracts (sorghum) with reduced rate of herbicides to control weeds in maize help to increase the growth of plants by increment in plant height and crop growth rate. Reduction in weeds densities reduced fresh and dry weights of weeds and improvement in weeds control efficiency (%) reduced the competition of weeds with maize for resources. It might increase the growth of maize and ultimately enhanced the grain yield. Sorghum allelopathic tretaments reduced the dry weight as well (Table-2). Thus, in view of the results, it can be interpreted that various allelopathic interactions might have exuded strong allelochemicals capable of inhibiting the growth of weed species in the vicinity. Similar results have already been presented by (Iqbal et al. 2010, Hozayn et al. 2011 and Kamran et al. 2016) who witnessed efficient weed control through allelopathic treatments. Similarly, (Iqbal et al. 2020) indicated that sorghum + brassica water extract maximally curtailed the green and dry biomass of T. portulacastrum and C. rotundus.

Reports have been presented by (Khaliq et al. 2004 and Khaliq et al. 2010) wherein they have recommended the use of sorghum allelopathy for weed control and have also suggested that crop performance may be bettered through using the same. Shahzad et al. (2021) reported similar results for label dose of Pendimethaline and its 50 and 75% dose combined with sorghum plant aqueous extract. The soil health improved by application of sorghum extract and sorghum mulch as compared to T1 (control) and T8 (chemical weed control). Integrated weeds management T6 and T7 reduced the PH and salinity and increments in organic matter and soil nitrogen. The allelopathic compound released from extract and mulch in soil come in contact with weeds, may kill and suppress the weeds. After decomposition of vegetative material, residue of crops and weeds incorporated in soil might bring the improvement in soil health. It is also described by Khan et al. (2012) and Bugio et al. (2013).

CONCLUSION

The study concluded that the weed species viz. T. portulacastrum, C. rotundus and E. colona were efficiently controlled with sorghum allelopathy, which in turn enhanced the 1000-grains weight and grain yield in maize as well. Keeping the promising results of sorghum allelopathic treatments, it was inferred that addition of sorgaab with half dose of atrazine might prove a better option for subjugating weed population in maize which also gave better economic returns with lesser risks of environmental deterioration.

CONFLICT OF INTEREST

We declare that we have no conflict of interest.

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AUTHOR CONTRIBUTIONS

IH, S and RA performed the experimental work. MYK and SA wrote the manuscript. JHS, QAJ and RAR assisted throughout the allelopathy survey, MH and GR performed statistics. MAG and IA designed the experimental work and assisted throughout the experimental as well as theoretical work.

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