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ORIGINAL ARTICLE

Weed control in sesame (*Sesamum indicum* L.) using integrated soil applied herbicides and seed hydro-priming pretreatment

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Abstract
This study explores the effects of the pre-emergence herbicides alachlor (1680; 2400 g ha^{-1}) and trifluralin (720; 1200 g ha^{-1}), the post-emergence herbicides bentazone (360; 480 g ha^{-1}) and haloxyfop (250; 375 g ha^{-1}) and their combinations, along with the effect of seed hydro-priming on weed control, growth and yield of sesame (*Sesamum indicum* L.). Hydro-priming reduced the interval from planting to seedling establishment, increased the seedling dry weight and the crop grain yield. Based on grain yield, 720 g ha^{-1} trifluralin followed by 250+720 g ha^{-1} holoxyfob + trifluralin, 250 +1680 g ha^{-1} holoxyfob + alachlor, 2400 g ha^{-1} alachlor, and 1680 g ha^{-1} alachlor, all combined with priming, were the best treatments. The results showed that proper combination of pre- and post-emergence herbicides along with seed priming could be used to control the weeds in the sesame and obtain seed yield comparable with weed-free conditions.

Key words: sesame; weed control; hydro-priming; herbicide; seed yield

INTRODUCTION

Sesame is widely used in the food, pharmaceutical and other industries in many countries due to its high oil, antioxidant and protein contents. Sesame was a major oilseed in the ancient world because of its easy extraction, great stability, and drought resistance (Bedigian and Harlan 1986). However, planting sesame seeds is difficult because the seeds are small and need to be placed precisely in the soil. Mechanisation of sesame cultivation therefore requires good weed control for 50 to 60 days after planting (Langham et al. 2007). Sesame cotyledons are also small when they emerge compared to other crops and do not grow as fast. Consequently, the presence of weeds can reduce the sesame yield (Ibrahim et al. 1988, Beltrao et al. 1991, Grichar et al. 2001a, b). Reduction of up to 65% in sesame yield has been reported and sesame needs a critical weed-free period of up to 50 days after planting (Hussein et

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al. 1983, Beltrao et al. 1991, Grichar et al. 2001a, b). In addition, sesame seed is similar to the size of many weed seeds, therefore, cleaning of the seeds may be difficult and some of the weed seeds may be toxic; sesame seeds in some markets require 99.99% purity.

A review of the literature has revealed limited research, and inconsistencies in the phytotoxicity of herbicides on sesame. Some researchers have shown that sesame yield was increased by the application of metolachlor and trifluralin (Hussein et al. 1983) or was not affected by S-metolachlor (Grichar et al. 2001b). In other studies, metolachlor adequately controlled weeds but caused unacceptable crop injury or reduced the sesame plant stands and caused sesame stunting when compared with the untreated check in one of two years (Langham et al. 2007, Grichar et al. 2009). Diuron was reported to have reduced the yield or controlled weeds without significant reduction in the yield (Langham et al. 2007). However, further works showed that diuron caused leaf chlorosis and stand reductions (Culp and McWhorter 1959), and yet another study has shown that the effect of diuron application with pendimethalin and alachlor was dose-specific and greater phytotoxicity was noted with the highest dose (Beltrao et al. 1991). However, there was no significant difference in the height of the first fruiting branch, the number of capsules per plant, and the yield between herbicides.

One approach to weed management in sesame could be seed priming. Priming is reported as the most important approach to improving seed germination parameters. It is a technique by which seeds gain physiological and biochemical preparation for germination before planting and encountering environmental ecological conditions (Afzal et al. 2002, Ahmadi et al. 2007). Several researchers (McDonald 2000, Afzal et al. 2002, Hussain et al. 2006) have shown that priming improved seed germination behaviour and its related indices including the germination mean period, seed viability, rootlet length, shootlet length, germination rate and primary establishment of crop.

There is a lack of comprehensive data on the effect of hydro-priming on early sesame development under farm conditions and weed control at this stage. Therefore, with weak seedling vigour, limited competitive ability, a lack of cheap labour and difficulty with separating sesame seeds from weed seeds, particularly toxic weed seeds, the use of seed and seedling enhancement treatments and proper herbicide combinations are essential for commercial mechanised sesame seed production. Hence, our present research was carried out to investigate the effect of pre- and post-emergence herbicides under hydro-priming seed pretreatment on sesame seed yield and weed control under field conditions.

MATERIALS AND METHODS

The research was carried out in the Agricultural Experimental Station, Isfahan University of Technology, located in the Lavark region of Najaf Abad County, Isfahan, Iran, in 2010. A factorial experiment based on a randomized complete block design with three replications was used. The tested treatments were thirteen herbicide combinations along with two check treatments, weed infested and weed-free, and seed hydro-priming (primed seeds by hydro-priming and unprimed seeds). We tested pre-emergence herbicides (Alachlor (1680 or 2400 g ha^{-1} from commercial formulation of Lasso) and trifluralin (720, 1200 g ha^{-1} from the commercial formulation of Treflan), two post-emergence herbicides: bentazone (360, 480 g ha^{-1} from commercial formulation of Bazagran), haloxyfop (250, 375 g ha^{-1} from the commercial formulation of Gallant) and their combinations.

Weather data during the growing season are shown in Table 1. Soil type was a clay loam with a bulk density of 1.4 g cm^{-3} and pH of 7.4. The year before the trials, the land had been fallow, and the level of fertilizers required was determined by a soil test. Tillage consisted of autumn moldboard plowing to a depth of 20 to 25 cm, followed by spring disking and harrowing. Sesame seed was sown by hand on 26 July 2010. Each trial plot was 5 × 2.5 m, with 5 rows spaced 50 cm apart, and the distance between plants within rows was 5 cm. To avoid herbicide drift between adjacent plots, borders of 1 m between the plots and 3 m between the blocks were maintained. The experiments were conducted utilising natural weed infestations. Plots were irrigated every 7 to 10 days to prevent soil moisture stress. No insecticides or fungicides were applied.

Table 1. Mean air temperature (°C) and relative humidity (%) in 2010 at the research farm of Isfahan University of Technology in the Lavark region of Najaf abad country, Isfahan, Iran

Month	Mean temperature (°C)	Mean relative humidity (%)
June	26.0	16
July	30.19	14
Aug	26.19	18
Sep	25.8	24
Oct	24.5	24
Nov	11.3	37

Seeds were hydro-primed in distilled water at 25 °C for 16 h and then re-dried to the original moisture content and prepared for cultivation. Pre-emergence herbicides were applied immediately after planting and the post-emergence herbicides were uniformly applied using a backpack sprayer at 6–8 leaf stages of sesame, with a spraying volume of 300 liters per hectare.

Days from sesame sowing to emergence were recorded, as were the shootlet and rootlet dry weight of the sesame crop 15 days after the emergence of the sesame seedlings. Weed numbers and their dry weight were measured separately for each species at three stages (before applying post-emergence herbicides, at the pollination period and at the physiological maturity period of sesame) using a quadrate 1 × 1 m. The samples were dried in an oven at 75–80 °C for about 48 h, and then weighed immediately. In the maturity stage of sesame plants, 2.7 m^2 of plots were harvested, dried and the seed and dry matter determined. The harvest index was obtained from grain yield/biological yield ratio.

Finally, the data collected for each trait were subjected to analysis of variance using the software program SAS. A means comparison was conducted using LSD at a probability level of 0.05.

RESULTS

Sesame establishment

Hydro-priming increased rootlet, shootlet and seedling dry weights, but reduced days to emergence. The period from planting to emergence was shortened for about 2.5 days by priming (Table 2).

Table 2. Effect of sesame seeds hydro-priming on mean weight of total seedling, rootlet and shootlet and on days to sesame emergence

Experimental factor	Seedling weight (g m^{-2})	Shootlet weight (g m^{-2})	Rootlet weight (g m^{-2})	Days to emergence
Primed	0.824^a	0.276^a	0.0161^a	7.48^a
Unprimed	0.619^b	0.200^b	0.0096^b	9.92^b

Note: For each column, superscripts, which have at least one letter in common, have no significant difference at probability level of 5%.

Application of both pre-emergence herbicides alachlor and trifluralin increased rootlet, shootlet, and seedling weights, but reduced days to emergence as compared with the control; however, there was no significant difference between the application rates of alachlor (Table 3).

Weed control

The main weed species in this experiment were *Echinochloa crus-galli, Chenopodium album* and *Amaranthus retroflexus* which competed successfully with sesame (Table 4). Weed density was reduced from 94.8 (alachlor rate 1680 g ha^{-1}) to 100% (trifuralin 720 g ha^{-1}) at the stage before application of post-emergence herbicides, while weed density was reduced from 31.6 (bentazone 480 g ha^{-1}) to 89.1% (bentazon + trifuralin at 360 and 720 g ha^{-1}) at the beginning of the pollination stage (Table 5). Weed density, however, was reduced from 24.5 (haloxyfob 250 g ha^{-1}) to 86.8%

(bentazone + alachlor at 360 and 720 g ha^{-1}) at physiological maturity stage. There was no significant difference between the application of bentazon + trifuralin (360 and 720 g ha^{-1}) and bentazone + alachlor (360 and 720 g ha^{-1}) on weed density reduction at all three stages (Table 5). Sesame seed priming had no significant effect on weed density reduction at all three sampling periods (data are not shown).

Table 3. Effect of herbicide treatments on mean weight of total seedling, rootlet and shootlet and on days to sesame emergence

Herbicide treatments	Herbicide rates (g ha^{-1})	Seedling weight (g m^{-2})	Shootlet weight (g m^{-2})	Rootlet weight (g m^{-2})	Days to emergence
Trifluralin	1200	0.603^{b}	0.241^{b}	0.0125^{b}	8.59^{b}
Trifluralin	720	0.798^{a}	0.330^{a}	0.0156^{a}	7.92^{a}
Alachlor	2400	0.791^{a}	0.323^{a}	0.0159^{a}	7.69^{a}
Alachlor	1680	0.793^{a}	0.318^{a}	0.0149^{a}	7.73^{a}
Untreated	None	0.591^{c}	0.106^{c}	0.0096^{c}	9.92^{c}

Symbols as in Table 2

Table 4. Weed species, family names and their intensity of infestation in the experimental plots

Weed species	Family of weeds	Intensity of weeds
Amaranthus retroflexus L.	Amaranthaceae	high
Echinchloa crus-galli	Poaceae	high
Chenopodium album L.	Chenopodiacea	high
Convolvulus arvensis L.	Convolvulaceae	low
Malva parviflora L.	Malvaceae	low

Table 5. Effect of herbicide treatments on mean total weeds density reduction (WDR) in three samplings conducted before application of post-emergence herbicides (BAPH), at beginning of pollination (BP) and at physiological maturity (PM)

Herbicide treatment	Rates (g ha^{-1})	WDR (%) at BAPH	WDR (%) at BP	WDR (%) at PM
Weed-free		100.0^{a}	100.0^{a}	100.0^{a}
Alachlor	2400	95.9^{a}	74.6^{cd}	73.7^{c}
Alachlor	1680	94.8^{a}	68.8^{f}	71.3^{c}
Trifluralin	1200	98.6^{a}	69.8^{ef}	71.9^{c}
Trifluralin	720	100.0^{a}	71.7^{def}	72.8^{c}
Haloxyfop	375	–	33.4^{h}	24.5^{e}
Haloxyfop	250	–	32.9^{h}	25.1^{e}
Bentazone	480	–	31.6^{h}	26.1^{e}
Haloxyfop+Trifluralin	250+720	96.6^{a}	73.7^{cde}	79.5^{b}
Haloxyfop+Bentazone	250+360	95.7^{a}	39.5^{g}	58.8^{d}
Haloxyfop+Alachlor	250+1680	98.5^{a}	76.8^{c}	73.1^{c}
Bentazone+Trifluralin	360+720	94.9^{a}	89.1^{b}	84.2^{b}
Bentazone+Alachlor	360+1680	96.7^{a}	86.9^{b}	86.8^{b}
Weed infestated		0	0^{i}	0^{f}

Symbols as in Table 2

Dry matter and grain yields

Seed priming increased sesame dry matter and grain yields, but had no significant effect on harvest index (Table 6). The application of 720 g ha^{-1} trifluralin produced the highest grain yield followed by weed-free, holoxyfob + trifluralin (250 and 720 g ha^{-1}), holoxyfob + alachlor (250 and 1680 g ha^{-1}), alachlor at 2400 g ha^{-1} and alachlor at 1680 g ha^{-1} (Table 7). Whereas, the weed-free variant produced the highest dry matter followed by the application of 720 g ha^{-1} trifluralin, 2400 g ha^{-1} alachlor, 250+720 g ha^{-1} holoxyfob + trifluralin, 1680 g ha^{-1} alachlor and 250+1680 holoxyfob + alachlor (Table 6). None of the treatments had significant effects on the harvest index (Table 7).

Table 6. Effect of hydro-priming on sesame mean dry matter yield, grain yield and harvest index

Experimental factor	Dry matter yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index (%)
Primed	5910.9^{a}	987.44^{a}	16.8^{a}
Unprimed	5529.1^{b}	894.17^{b}	16.1^{a}

Symbols as in Table 2

Table 7. Effect of herbicide treatments on sesame mean dry matter, grain yield and harvest index

Herbicide treatments	Rate (g ha^{-1})	Grain yield (kg ha^{-1})	Dry matter yield (kg ha^{-1})	Harvest index (%)
Weed free		1119.97^{a}	6726.2^{a}	16.64^{a}
Alachlor	2400	1091.52^{ab}	6623.3^{a}	16.49^{a}
Alachlor	1680	1077.59^{ab}	6537.7^{a}	16.53^{a}
Trifluralin	1200	923^{d}	6155.5^{b}	14.99^{a}
Trifluralin	720	1124.08^{a}	6637.1^{a}	16.92^{a}
Haloxyfop	375	768.53^{e}	4753.3^{cd}	16.19^{a}
Haloxyfop	250	767.13^{e}	4751.2^{cd}	16.18^{a}
Bentazone	480	749.47^{e}	4772.7^{c}	15.59^{a}
Bentazone	360	742.18^{e}	4441.2^{e}	17.03^{a}
Haloxyfop+Trifluralin	250+720	1117.74^{a}	6578.1^{a}	16.95^{a}
Haloxyfop+Bentazone	250+360	738.01^{e}	4655.6^{cde}	17.28^{a}
Haloxyfop+Alachlor	250+1680	1098.28^{ab}	6526.1^{a}	16.71^{a}
Bentazone+Trifluralin	360+720	1025.94^{bc}	5964.4^{b}	17.28^{a}
Bentazone+Alachlor	360+1680	986.24^{cd}	6151.4^{b}	16.07^{a}
Weed infestated		670.12^{e}	4490.2^{de}	16.10^{a}

Symbols as in Table 2

The interaction effect of hydro-priming and herbicide on grain and dry matter yield was significant (Table 8). Priming under weed-free conditions produced the highest dry matter followed by the application of 2400 g ha^{-1} alachlor with priming, 1680 g ha^{-1} alachlor with priming, 720 g ha^{-1} trifluralin with priming, 250 +1680 g ha^{-1} holoxyfob + alachlor, and 250+720 g ha^{-1} holoxyfob + trifluralin. Priming under weed-free conditions produced the highest grain yield followed by the application of 720 ha^{-1} trifluralin, 250+720 g ha^{-1} holoxyfob + trifluralin, 250 + 1680 g ha^{-1} holoxyfob + alachlor, 2400 g ha^{-1} alachlor and 1680 g ha^{-1} alachlor; all the variants were combined with priming (Table 8).

Table 8. Effect of herbicide treatments and seed hydro-priming on sesame mean dry matter yield and grain yield

Experimental treatments	Rates (g ha^{-1})	Seed priming treatment	Dry matter (kg ha^{-1})	Grain yield (kg ha^{-1})
Weed free		Primed	7206.9^{a}	1225.56^{a}
		Unprimed	6245.5^{cde}	1014.37^{cde}
Alachlor	2400	Primed	7113.2^{a}	1165.85^{a}
		Unprimed	6133.4^{de}	1017.19^{cde}
Alachlor	1680	Primed	7087.0^{a}	1138.33^{ab}
		Unprimed	5988.5^{ef}	1016.86^{cde}
Trifluralin	1200	Primed	6203.7^{de}	937.15^{cdef}
		Unprimed	6107.3^{de}	908.85^{ef}
Trifluralin	720	Primed	7048.9^{a}	1217.94^{a}
		Unprimed	6226.6^{de}	1030.23^{bcd}
Haloxyfop	375	Primed	4647.8^{ijk}	756.60^{ghij}
		Unprimed	4858.8^{jhi}	780.46^{ghi}
Haloxyfop	250	Primed	4467.7^{kl}	750.48^{ghij}
		Unprimed	4645.7^{ijk}	783.78^{ghi}
Bentazone	480	Primed	4634.4^{ijk}	743.90^{ghij}
		Unprimed	4911.0^{hi}	740.46^{ghij}
Bentazone	360	Primed	4528.9^{jki}	830.52^{fgh}
		Unprimed	4536.6^{kl}	741.41^{ghij}
Haloxyfop+Trifluralin	250+720	Primed	6937.1^{ab}	1211.79^{a}
		Unprimed	6219.2^{de}	1023.68^{cd}
Haloxyfop+Bentazonee	250+360	Primed	4160.0^{l}	837.90^{fg}
		Unprimed	5151.3^{h}	758.12^{ghij}
Haloxyfop+Alachlor	250+1680	Primed	6976.7^{a}	1186.15^{a}
		Unprimed	6147.6^{de}	1010.41^{cde}
Bentazonee+Trifluralin	360+720	Primed	6391.1^{cd}	1040.31^{bc}
		Unprimed	5537.7^{g}	1011.57^{cde}
Bentazonee+Alachlor	360+1680	Primed	6603.3^{bc}	1041.71^{bc}
		Unprimed	5698.9^{fg}	930.77^{def}
Weed infestated		Primed	4658.4^{ijk}	717.31^{ij}
		Unprimed	4323.4^{kl}	727.39^{hij}

Symbols as in Table 2

DISCUSSION

Hydro-priming of sesame seeds enhanced seedling growth and reduced the interval between planting and emergence as compared with the unprimed seeds. That may have been due to the increased activities of alpha- and beta-amylases and also the increased amount of water absorbed by the seed by priming as reported by Hussain et al. (2006). In line with our results, Hussain et al. (2006) reported that priming eventually increased the germination percent, accelerated the emergence rate and also improved the germination condition. The increase in seedling growth and the reduction of the planting to emergence interval, could also be a result of the increase in the germination substrate for the vigorous and earlier production of seedlings by priming. Priming also increased the dry matter and grain yield that was due to the increase in seedling growth and reduction in days from planting to emergence as indicated in Table 2. In accordance with our results, Hussain et al. (2006) reported that hydro-priming increased the growth and seed yield of sunflower.

Bentazone as a post-emergence herbicide combined with pre-emergence herbicides alachlor or trifluralin had the highest efficiency in reducing weed density and controlled grass and broadleaf weeds across the growing season. The application of the post-emergence herbicide individually had lower efficiency on weed control. The application of pre-emergence herbicides was thus accentuated. Similar results on the lack of difference in applied herbicide levels in have been reported. (Grichar and Peter 2007). Full season weed competition reduced yield after weed control treatment to about 48% of the weed-free season. The results of our present research imply that weeds are able to reduce sesame grain yield considerably by competing with the crop. Sesame yield losses due to its competing with weeds have been estimated as up to 135% compared to the weed-free treatment (Balyan 1993). In most of the reports, it could be concluded that the highest sesame yield losses were due to its lack of competition to weeds at early growth stage. In this study, a low yield in post-emergence treatment was presumably caused by the lack of weed control in the early growth stage. As a result, sesame competed with weeds before the application of post-emergence herbicides. It seems that the application of post-emergence herbicides without the addition of pre-emergence ones had no effect on grain yield. Thus, it is essential to use pre-emergence herbicides to control sesame weeds. Other research has shown sesame susceptibility to post-emergence herbicides but a toleration of haloxyfop (Langham 2008). The application of haloxyfop has been recommended where there is an outbreak of grass weed in the sesame field (Langham 2008). The herbicide alachlor was successful in controlling weeds without any damage to the sesame. The interaction of seed hydro-priming and the application of herbicides on the sesame yield was significant. It seems that sesame seed priming could strengthen seedling germination and establishment, and create a relative resistance against herbicides by improving the growth parameters. Most studies suggest a positive priming effect on resistance to adverse environmental conditions (Demir et al. 2006). The results of a study (Baalbaki et al. 1999) have indicated that priming improved drought resistance in plants at the germination emergence stage. Another experiment has shown that priming increased chickpea yield (Kaur et al. 2002).

Although combined treatments of bentazone with pre-emergence herbicides could control weed more efficiently, bentazone caused a reduction in sesame yield. In accordance with our results, Grichar et al (2001b) observed that sesame yield was reduced by 62% when compared with weed free control under bentazone application. Punia et al. (2001) proved that low doses of trifluralin acted selectively on sesame and appropriately controlled the weeds but in high doses it had an undesirable effect on sesame. Also in the present research, the application of trifluralin at 1200 g ha^{-1} damaged sesame; hence high doses of this herbicide cannot be recommended.

Based on the reduction of weed density, bentazon plus trifluralin (360 +720 g ha^{-1}) and bentazon + alachlor (360+1680 g ha^{-1}) were the most effective treatments, whereas the best treatments, based on grain yield production, were 720 g ha^{-1} trifluralin with priming followed by 250+720 g ha^{-1} of holoxyfob + trifluralin with priming, 250+1680 g ha^{-1} of holoxyfob + alachlor with priming, 2400 g ha^{-1} of alachlor with priming, and 1680 g ha^{-1} of alachlor with priming. We do not advise the use of the bentazone herbicide in sesame weed management because of crop phytotoxicity and reduction in sesame yield. The results showed that a proper combination of pre- and post-emergence herbicides along with seed priming could be used to control the weeds in sesame and to obtain a seed yield comparable with weed-free conditions.

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