RESEARCH

Impact of PRE- and POST herbicide on purple nut sedge (*Cyperus rotundus* L.) control and plasticulture tomato yields

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ABSTRACT

Purple nut sedge (*Cyperus rotundus* L.) is a problematic weed in plasticulture tomato (*Solanum lycopersicum* L.) production in Iran as it is difficult to control due to its ability to penetrate plastic mulch. Field trials were carried out at the experimental area of the state farm Safadasht, Shahriar region, Iran, over the fall of 2015 and spring of 2016 to investigate PRE- and POST herbicide programs (PRE transplanting, POST transplanting, and combination of PRE- and POST transplanting) to control purple nut sedge in plasticulture tomato production. PRE herbicide treatment metribuzin and (*S*)-metolachlor were not effective when applied alone, and did not reduce purple nut sedge plants compared to the weedy control. POST transplanting application of halosulfuron did not significantly affect purple nut sedge plants at 12 wk after application (WAA) in the fall 2015, but treatment favorably reduced density of purple nut sedge at 16 WAA in both seasons. PRE transplanting application of metribuzin or (*S*)-metolachlor plus POST halosulfuron exerted the greatest control, and purple nut sedge numbers were eventually diminished in both seasons. Experimental treatments did not negatively affect tomato height and yields. Based on our findings, multiple PRE and POST herbicide programs were effective in greater purple nut sedge suppression compared to the lone application of PRE and POST herbicides. The herbicides were selected due to routine use by tomato producers in the area. Using active ingredients from the various herbicide families with different modes of action could facilitate effective management of herbicide-resistant purple nut sedge in tomato fields.

Key words: Plasticulture, PRE- and POST herbicides, purple nut sedge, tomato, weed control.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the principal vegetable crops produced in Iran with an annual output of approximately 150 million tons (Shirdel et al., 2014; Zenga et al., 2020). The use of polyethylene mulch in crop production can significantly increase yield, minimize nutrient leaching, enable sustainable vegetable production and lessen herbicide dependence and total application. In tomato production, polyethylene mulches provide considerable control of most grass and broadleaved weeds; nonetheless, these weeds generally appear through the planting hole in the mulch (Dittmar et al., 2010; Mafakheri et al., 2012). Purple nut sedge (*Cyperus rotundus* L.) has been found to be a problematic weed menacing plasticulture tomato cultivation, since it emerges through the crop hole and also perforates the polyethylene mulch (Adcock et al., 2008; Dittmar et al., 2012). Boyd (2016) validated that purple nut sedge pierces through the plastic mulch between the tomato rows and emerge through the crop holes.

POST herbicides are necessary for nut sedge control, nonetheless few herbicides can be safely used pre or post transplant in tomato cultivation (Manning and Fennimore, 2001; Boyd, 2016; Merino et al., 2020). For this reason, most farmers apply PRE transplanting herbicides such as metribuzin and (*S*)-metolachlor (Devkota et al., 2013), and POST transplanting herbicides such as halosulfuron (Haar et al., 2002) for nut sedge suppression (Freeman et al., 2016; Boyd and Dittmar, 2018). Halosulfuron is an active ingredient belonging to the sulfonylurea group with varying levels of purple nut sedge control in tomato and other vegetable crops. Adcock et al. (2008) reported effective control of nut sedge weed population due to POST transplant application of halosulfuron. A study by Vencill et al. (1995) exhibited nonsignificant difference in weed biomass, shoots and roots of purple nut sedge when halosulfuron was applied either to foliage or the soil. The plasticulture production approach is generally dependent on herbicide use, since cultivation is hindered by the presence of the polyethylene mulch. Hence, to achieve optimum weed management several herbicide applications are required. POST herbicide options such as glyphosate application prior to sowing are favored by farmers (Vasilakoglou et al., 2018). Various PRE- and POST active ingredients are registered for purple nut sedge and yellow nut sedge (*Cyperus esculentus* L.) control (Pereira et al., 1987; Boyd and Dittmar, 2018). These herbicides only provide inconsistent or short-term control of nut sedge plants (Dittmar, 2013; Bayat et al., 2019).

Halosulfuron is a safe and pragmatic POST transplant herbicide in tomato fields (Jennings, 2010; Pliushchikov et al., 2019), and is a viable option used in various PRE- and POST combinations for prolonged purple nut sedge suppression. Herbicide programs integrating both PRE and POST herbicides are highly recommended for effective control of nut sedge weeds. For instance, Boyd and Dittmar (2018) stated that spraying (*S*)-metolachlor combined with halosulfuron in tomato fields significantly reduces nut sedge weed density. Moreover, Devkota et al. (2013) reported satisfactory yellow nut sedge control up to 90% owing to the application of PRE (*S*)-metolachlor plus POST trifloxysulfuron or halosulfuron.

There is need to identify the most effective multiple herbicide programs for purple nut sedge control in plasticulture tomato cultivation. The principal objective of this study was to investigate the efficacy of multiple PRE transplanting herbicides applied alone or followed by the POST herbicide halosulfuron in plasticulture tomato production.

MATERIALS AND METHODS

Site description, experimental design, and site management

This study consisted of two field experiments that were laid out in separate experimental fields in west of Tehran namely Shahriar region (50°50' E, 35°40' N; 1130 m a.s.l.), Iran, in 2015 and 2016. Soil samples were randomly taken from each replicate and from each experiment, at a depth of 25 cm before sowing. The samples were dried at 55 °C, ground, and analyzed by standard methods (Clemson University Agricultural Service Laboratory, Clemson, South Carolina, USA). The soil was classified as loamy sand (fine-loamy, thermic Typic Kandiudults) with a pH of 6.4 and organic matter of 1.1%.

Experiments were conducted in a randomized complete block design with four blocks. Plots were 0.85 m wide raised beds measuring 6 m in length. Beds were prepared in the middle of July 2015 (fall) and the end of January 2016 (spring). A single drip tape was installed in the center at 3 cm below the soil surface. All beds were fumigated with 220 kg ha^{-1} 40% 1,3-dichloroprop-1-ene plus trichloro(nitro)methane (Pic-Clor 60, TriCal Inc., Hollister, California, USA) using a three-shank fumigation rig. Holes were punched in a single row with 0.60 m spacing with a mechanical hole puncher. Tomato (*Solanum lycopersicum* L.) 'Ezmir' was transplanted after punching the sowing holes on 27 August 2015 and 3 March 2016. Herbicides involved the POST transplanting active ingredient halosulfuron (3-chloro-5-[(4,6-dimethoxypyrimidin-2-yl)carbamoylsulfamoyl]-1-methylpyrazole-4-carboxylic acid) at 48 g ai ha^{-1}, and two PRE transplanting herbicides metribuzin (4-amino-6-*tert*-butyl-3-methylsulfanyl-1,2,4-triazin-5-one) 550 g ai ha^{-1} and (*S*)-metolachlor (2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-[(2*S*)-1-methoxypropan-2-yl]acetamide) 1020 g ai ha^{-1}. A detailed description of herbicide treatments is given in Table 1.

Following soil fumigation, PRE transplanting herbicides were applied and beds were immediately covered with plastic mulch. The POST transplanting herbicide halosulfuron was applied on tomato plants when tomato plants were at flowering stage. All herbicide treatments were sprayed with a backpack sprayer (Bellspray Inc., Opelousas, Louisiana, USA) with a pressure of 0.25 MPa. Its boom was fitted with a single 8002VS nozzle (TeeJet Technologies, Wheaton, Illinois, USA) and herbicides were applied at a spray volume of 210 L ha^{-1} water. Weedy control plots were conducted in each replicate of each experiment for comparison. In the weedy control, no weeding was done. Herbicides were sprayed on both sides of the bed and directly at the base of the tomato plants.

Table 1. Herbicide treatments applied PRE- and POST transplanting at the base of tomato plants at Shahriar region, Iran, in 2015 and 2016.

Active ingredient	Rate (g ai ha^{-1})	Mode of action	Chemical name	Manufacturer
PRE				
Metribuzin	550	Photosystem II inhibitor	4-amino-6-*tert*-butyl-3-methylsulfanyl-1,2,4-triazin-5-one	Bayer CropScience, Research Triangle Park, North Carolina (http://www.cropscience.bayer.us)
(*S*)-Metolachlor	1020	Long chain fatty acid inhibitor	2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-[(2*S*)-1-methoxypropan-2-yl] acetamide	Syngenta Crop Protection Inc., Greensboro, North Carolina, USA
POST				
Halosulfuron	48	ALS inhibitor	3-chloro-5-[(4,6-dimethoxypyrimidin-2-yl)carbamoylsulfamoyl]-1-methylpyrazole-4-carboxylic acid	Gowan Company, Yuma, Arizona, USA (http://gowanco.com)

ALS: Acetolactate synthase.

Crop injury was estimated visually 2 and 4 wk after application (WAA) using a scale from 0% to 100% (0% no injury and 100% plant death) (Chaudhari et al., 2015). Chlorosis, necrosis, and leaf deformation were surveyed according to visual injury estimates. Tomato fruits were harvested on 28 November and 8 December 2015, and 27 May and 10 June 2016.

Tomatoes were graded according to diameter prior to weighing as small (5.4-6.4 cm diameter), large (6.4-7.0 cm) and x-large (> 7.0 cm). Marketable yield was the sum of the three fruit grades (Anonymous, 1991). Purple nut sedge shoots in whole plots were counted 4, 12, and 16 WAA in 2015 and 4 and 16 WAA in 2016. 6.5 to 7 cm diameter.

Statistical analysis

Data was analyzed in SAS version 9.2 (SAS Institute Inc., Cary, North Carolina, USA) using a mixed procedure with the block as the random factor. Data was checked for normality and constant variance prior to analysis. Experiments were analyzed separately as they were conducted in separate years and climate conditions were different between seasons. Treatment means were compared with the Tukey adjustment means of comparison at the 0.05 significance level. Tomato injury data was recorded at multiple dates and was analyzed with the function of the repeated statement.

RESULTS AND DISCUSSION

PRE and POST transplanting herbicide application had a significant effect on purple nut sedge control in both seasons. The PRE transplanting herbicides metribuzin and (*S*)-metolachlor did not decrease the presence of purple nut sedge plants compared to the weedy control when they were applied alone (Table 2). The lowest purple nut sedge control was detected for PRE transplanting herbicide metribuzin at all evaluation timings in 2015 and did not differ from the weedy control; however, this herbicide favorably reduced the purple nut sedge population at 16 WAA in 2016. POST transplanting application of halosulfuron did not reduce nut sedge counts significantly at 12 WAA in 2015; but, this herbicide reduced purple nut sedge plants at 16 WAA in 2015 and 2016 (Table 2).

Overall, the highest purple nut sedge control was attained when PRE transplanting herbicides metribuzin or (*S*)-metolachlor were applied in combination with POST halosulfuron application compared to the PRE transplanting treatments sprayed alone in 2015. Hence, weed control efficacy of all herbicide treatments at 16 WAA, except (*S*)-metolachlor, were similar to the weedy control and effectively diminished purple nut sedge density. (*S*)-metolachlor can significantly control nut sedge numbers (Adcock et al., 2008; Dittmar, 2013; Boyd, 2016), but this was not obtained in our study. Poor nut sedge control was due to the fact that some of the nut sedge plants had already emerged at the time of spray.

Weed control results indicated that density of purple nut sedge in 2015 was favorably higher than in 2016. Inconsistent weed control efficacy between seasons could be due to the variability of purple nut sedge density in experimental fields. In a study, Miller and Dittmar (2014) reported that control of a high density of nut sedge is difficult in plasticulture vegetable crops when relying on fomesafen or (*S*)-metolachlor PRE transplanting active ingredients alone. In our research, the herbicide combination composed of (*S*)-metolachlor or metribuzin as PRE transplanting herbicides with halosulfuron POST transplanting herbicide obtained the highest efficacy at almost all evaluation timings and consistently diminished the number of nut sedge plants.

Table 2. Purple nut sedge counts following herbicide treatments in plasticulture tomato in Shahriar, Iran, in 2015 and 2016.

Active ingredient	Timing	Field rate	2015			2016	
			4 WAA	12 WAA	16 WAA	4 WAA	16 WAA
		g ai ha^{-1}	Nr shoots^{-2}				
Weedy	–	–	55a	127a	115a	8a	11a
Halosulfuron	POST	48	76a	82ab	17b	6a	2b
Metribuzin	PRE	550	50a	82a	86a	5a	3b
Halosulfuron + metribuzin	POST+ PRE	48 + 550	18a	7c	3b	4a	2b
(*S*)-Metolachlor	PRE	1020	42a	98a	95a	6a	8ab
(*S*)-Metolachlor + halosulfuron	PRE + POST	1020 + 48	39a	15bc	2b	1a	1b
P-value	–	–	0.4412	0.0002	0.0025	0.1800	0.0091
Coefficient of variation, %	–	–	2.91	8.99	4.90	7.07	11.08

Means followed by different letters in each column are significantly different by Tukey's protected LSD (P ≤ 0.05).
WAA: Weeks after application.

Halosulfuron is an effective active ingredient for controlling purple nut sedge (Grichar et al., 2003; Freeman et al., 2016; Boyd and Dittmar, 2018; Yu et al., 2020). Halosulfuron is also effective for control of many different broadleaf and grass weeds in Iranian fields including goose grass (*Eleusine indica* [L.] Gaertn.), velvetleaf (*Abutilon theophrasti* L.) and barnyardgrass (*Echinochloa crus-galli* [L.] P. Beauv.) (Zand et al., 2011). The lowest level of nut sedge control was obtained when metribuzin or (*S*)-metolachlor were used alone in PRE transplanting applications (Table 2). In this regard, Boyd (2015) reported nut sedge control was inconsistent and varied over time and area when (*S*)-metolachlor was applied solely as PRE transplanting. Hence, application of the described PRE transplanting active ingredients alone in tomato fields might not be sufficient for long term sustainable weed management.

As a result, POST application of halosulfuron can provide purple nut sedge suppression after using PRE herbicides such as metribuzin or (*S*)-metolachlor (Yu et al., 2020). Blum et al. (2000) found that 35% to 70% nut sedge control was achieved through the use of a POST halosulfuron application in turf, whereas Grichar et al. (2003) indicated a 75% to 95% nut sedge control through a single application of halosulfuron in potato fields. Additionally, Bangarwa et al. (2009) reported that PRE transplant use of (*S*)-metolachlor provided about 80% yellow nut sedge control at 5 WAA, but this treatment had no favorable suppression efficacy on purple nut sedge density.

Effective weed management is critical in order to produce quality fruit at high levels of production (Zimdahl, 2004; Zargar et al., 2019a); as failure to do so can result in severe yield losses in tomato (Buckelew et al., 2006; Garvey et al., 2013). Visible yield injury results are given as an average of all evaluation timings in Table 3. Yield injury was ≤ 2% and plant height was not decreased by herbicide treatments. There was nonsignificant difference in tomato yield in all sampling dates. The critical weed-free period for tomato is about 5 wk after transplanting (Garvey et al., 2013),

Table 3. Visible injury and height affected by herbicide treatments in plasticulture tomato in Shahriar, Iran.

Active ingredient	Timing	Field rate	Yield injury		Plant height	
					2015	2016
			2015	2016	7 WAA	4 WAA
		g ai ha^{-1}	%		cm	
Weedy	–	–	0	0	95.1	16.2
Halosulfuron	POST	48	1	0	90.5	13.5
Metribuzin	PRE	550	0	0	86.2	12.0
Halosulfuron + metribuzin	POST+ PRE	48 + 550	0	0	86.2	13.8
(*S*)-Metolachlor	PRE	1020	0	1	90.5	14.2
(*S*)-Metolachlor + halosulfuron	PRE + POST	1020 + 48	2	0	89.3	14.1
P-value	–	–	0.0051	0.0887	0.1113	0.0002
Coefficient of variation, %	–	–	9.9	10.2	2.9	7.5

Means followed by different letters in each column are significantly different by Tukey's protected LSD (P ≤ 0.05).
WAA: Weeks after application.

Table 4. Efficacy of PRE- and POST transplanting herbicides on plasticulture tomato yield.

			2015				2016			
Active ingredient	Timing	Rate	Small	Large	x-large	Marketable	Small	Large	x-large	Marketable
		g ai ha^{-1}	kg plant^{-1}							
Weedy	-	-	0.70	1.30	6.70	8.70	0.24	1.01	2.85	4.10
Halosulfuron (halo)	POST	48	0.71	1.39	6.75	8.85	0.22	0.89	3.84	4.95
Metribuzin (met)	PRE	550	0.90	1.36	8.09	10.35	0.20	0.93	3.47	4.60
Halo + met	POST + PRE	48 + 550	0.84	1.05	6.31	8.20	0.25	0.45	3.95	4.63
(*S*)-Metolachlor (*S*-met)	PRE	1020	0.62	0.93	6.95	8.50	0.23	0.42	4.25	4.9
S-met + halo	PRE + POST	1020 + 48	0.64	0.99	7.02	8.65	0.26	0.54	3.98	4.78
P-value	-	-	0.2521	0.0022	0.0281	0.1524	0.6210	0.0009	0.8215	0.1256
Coefficient of variation, %	-	-	3.9	1.9	8.8	4.6	7.5	6.9	9.7	4.8

Tomatoes were graded prior to weighing as small (5.4 cm < diameter), large (6.4 cm < diameter < 7.0 cm) and x-large (> 7.0 cm). Marketable yield is the sum of the three fruit grades.
Means followed by different letters in each column are significantly different by Tukey's protected LSD ($P \leq 0.05$).

indicating that purple nut sedge emergence after this period would not result insignificant. Combining herbicides with different modes of action can prevent the evolution of herbicide-resistant weeds (Galon et al., 2018; Zargar et al., 2019b). Unfortunately, despite significant weed suppression, there was still a number of nut sedge plants that were able to survive and produce seeds; and this may complicate weed management practices in the future, especially when using active ingredients with a single mode of action.

Tomato fruit yield was significantly higher in 2015 than in 2016. Because of differences in climate and field condition at sowing date, tomato yields varied in the growing seasons of 2015 and 2016. POST halosulfuron (Jennings, 2010) and PRE (*S*)-metolachlor (Boyd, 2016) can be safely used in plasticulture tomato without negative impact on tomato productivity, as tomato is tolerant to these herbicides (Buker et al., 2004; Chintala et al., 2014). Application rates for herbicide treatments and also for weedy control are presented in Table 4.

Herbicides used in this research were selected because they are routinely used by farmers in the area. Overall, PRE transplant application of metribuzin and (*S*)-metolachlor alone did not provide significant or sufficient nut sedge reduction percent. POST transplant application of halosulfuron followed by the PRE transplant herbicides (*S*)-metolachlor or metribuzin tended to provide the highest weed suppression across both seasons.

CONCLUSIONS

According to our findings, these herbicide programs are safe to use on tomato plasticulture cultivation in Shahriar, Iran. Our results found that the combination of PRE and POST transplanting herbicides for purple nut sedge control are viable options in plasticulture tomato production. PRE metribuzin and (*S*)-metolachlor plus POST halosulfuron can provide sustainable nut sedge management in tomato fields. There was no differences in total marketable tomato, but, there was differences in diameter large in 2015 and 2016, and x-large in 2015. Overall, it is important reduce purple nut sedge shoots and this could impact future weed densities.

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