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Research Article

Saffron *Crocus sativus* L. tolerance to some herbicides

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Abstract: Although, weed control in saffron farms is critical, no herbicide is registered for saffron fields. This experiment was carried out in a randomized complete block design with three replicates during 2016-2017. Treatments included application of trifluralin, pendimethalin, metribuzin, bentazon, ioxynil, oxadiazon, oxyfluorfen, haloxyfop-r-methyl, sethoxydim, clethodim, cycloxydim, nicosulfuron, rimsulfuron, tribenuron methyl, foramsulfuron, paraquat, dicamba + triasulfuron, and dicamba + tritosulfuron herbicides at recommended and reduced doses. Mother corms were planted on 10th of September 2016 at 5 × 10 cm corms distance and planting depth of 15 cm. Measured indices included: number of flowers, fresh and dry weights of flower and stigma, number of replacement corms and total corms weight. Results showed that visual phytotoxic symptoms were not observed in pre emergence herbicides. Post emergence herbicides showed different levels of phytotoxicity from slight to severe. The application of paraquat, oxyfluorfen and oxadiazon, caused higher levels of phytotoxicity compared to other herbicides. Acetyl CoA carboxylase inhibitor herbicides caused the least injury to saffron, while acetolactate synthase inhibitor herbicides damaged saffron severely. The highest and the lowest dried stigma yield was obtained from control treatment (0.54 $g.m^{-2}$) and post application of tribenuron methyl (0.003 $g.m^{-2}$) respectively. Among pre emergence herbicides, the highest dried stigma yield was recorded for pendimethalin herbicide. The post application of metribuzin, oxadiazone and oxyfluorfen resulted in greater dried stigma yield than other broadleaf herbicides. By reducing herbicide dose saffron yield increased and phytotoxic levels were reduced significantly. Among the studied herbicides, trifluralin, oxyfluorfen, pendimethalin and metribuzin can be used as selected herbicides in saffron.

Keywords: Chemical control, Herbicide, Phytotoxicity, Saffron yield

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Introduction

Saffron *Crocus sativus* L. is a perennial plant which grows in some regions of the world such as Iran, Italy and Greece (Koocheki *et al.,* 2013). Saffron is cultivated in limited areas of the world. Iran, Greece, Morocco, Kashmir, Spain and Italy are the main countries dealing with Saffron production. Among these countries, Iran has more than 90% of the total world harvest area (Ghorbani, 2008). Saffron is a vulnerable crop to weed competition because of its short canopy and narrow leaves. So weeds are the major problem in saffron production (Rashed Mohassel, 1992). Weeds are mainly controlled mechanically or by hand in saffron fields. Although these traditional methods are

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effective and environmentally friendly, they are expensive and time consuming (Behnia, 1992; Kumar *et al.,* 2009). On the other hand, mechanical control may cause severe damage to saffron which results in yield loss, due to its narrow rows (25 cm row spacing) and this makes hand weeding more difficult (Soufizadeh *et al.,* 2006).

Although very little research has been done on chemical weed control, some new herbicides have been introduced for saffron. Post emergence application of herbicides such as metribuzin, haloxyfop-r- methyl ester (Abbasi, 1996; Norouzzadeh and Delghandi, 2006; Soufizadeh *et al.,* 2006) ioxynil (Norouzzadeh and Delghandi, 2006) and fluazifop-p-butyl (Abbasi, 1996; Vafabakhsh, 2001) had an acceptable efficacy in saffron weed control. In Poland, fluorochloridon and simazine applied in autumn, and cynazine and metamitron in spring were the most efficient weed control options (Hetman and Laskowska*,* 1992). Bullitta *et al. (*1996) also reported that chlorthal and glyphosate had satisfactory results in weed control in rows of saffron in Spain. Pendimethalin (Rana *et al.*, 1999), ethalfluralin (Abbasi 1996; Rahimian, 1993) and metribuzin (Sadrabadi Haghighi and Ghanad Tosi, 2016) are also recommended for weed control in saffron as pre-emergence. Abbassian *et al.* (2014) showed that tank-mix application of haloxyfop-r-methly with oxyfluorfen or metribuzin compared to ioxynil + haloxyfob-r-metyl could significantly conrol weeds in saffron fields.

Other reports indicated that iodosulfuron methyl sodium + mesosulfuron methyl + mefenpyr Diethy (WG6%) herbicides can efficiently control grassy and broadleaf weeds, while they injure saffron plant. Haloxyfop-r-methyl ester also damage grassy weeds but decrease stigma and leaf yields of saffron (Zare Hosseini *et al.,* 2014). Galavi and Sarrani (2006) reported that 2, 4-D + MCPA herbicides were rejected, because they severely damaged saffron which resulted in chlorosis and elongation of the leaves.

This study was carried out in order to evaluate the tolerance of saffron to several pre-emergence and post-emergence herbicides at recommended and reduced doses to find selective herbicides for control of saffron weeds.

Materials and Methods

The study was conducted in 2016–2017 growing seasons, at the Kashmar Agricultural and Natural Resources Research Center, (58° 27′E, 35°11′N, and 1052 m a.s.l.) Khorasan-Razavi, Iran on a silt-loamy soil (36% sand, 11% clay and 53% silt, 0.585% organic matter) with a pH 7.94 and EC 1.23 dS m^{-1}. Some local meteorological data for the growing seasons are presented in Fig. 1. A randomized complete block design with 38 treatments and three replicates was used. The treatments are described in table 1. The experimental field was prepared according to the local practice for saffron cultivation and then plots were established. Each plot was 4 m^2 (2 m long and 2 m wide) and 0.5 m apart. Between blocks, 1 m alley was kept to eliminate influence of treatments.

Saffron mother corms weighing 6-8 g were selected from Kashmar saffron farms and were planted on 10th of Sep. 2016 in rows spaced 5 x 10 cm apart and at a depth of 15 cm. Irrigation and fertilization of saffron was carried out according to the local practice for saffron production and no pesticides were used throughout the growing seasons. Pre-emergence herbicides were applied before crust crushing after the first irrigation on 12th of October 2016 directly onto soil and post herbicides were applied on 14th of February 2016. Herbicides were sprayed with an electric knapsack sprayer (MATABI) (Goizeper S. Cooperative Company, Guipuzcoa, Spain) fitted with 8002 VS flat fan nozzles, calibrated to deliver 300 L ha^{-1} of spray solution at a pressure of 2.5 KPa. To prevent spray drift and the adverse effects of the treatments on one another, adjacent plots were covered during spraying. Some characteristics of herbicides used in the experiment are shown in table 2.

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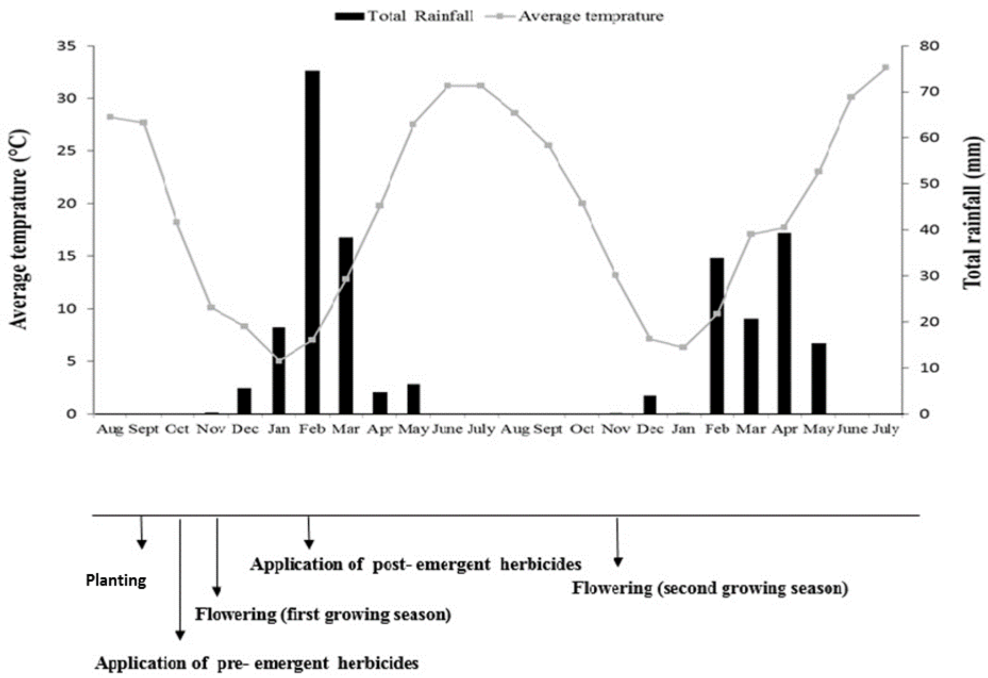

Figure 1 Monthly rainfall and average temperature during the two growing seasons (August 2016 until July 2018) at the I. R. of Iran Meteorological Organization (IRIMO).

Table 1 Dose and application time of herbicides used in the experiment.

Herbicide	Herbicides dose (g i.a.ha^{-1})[1]	Application time
Trifluralin	1200.00	Preemergence
Pendimethalin	1485.00	Preemergence
Metribuzin	700.00	Preemergence
Metribuzin	525.00	Postemergence
Metribuzin	**395.00**[2]	Postemergence
Trifluralin + Metribuzin	960.00 + 350.00	Preemergence
Oxadiazon	750.00	Preemergence
Oxadiazon	500.00	Postemergence
Oxadiazon	**375.00**	Postemergence
Oxyfluorfen	720.00	Postemergence
Oxyfluorfen	**505.00**	Postemergence
Haloxyfop-r-methyl	162.00	Postemergence
Haloxyfop-r-methyl	**120.00**	Postemergence
Sethoxydim	375.00	Postemergence
Sethoxydim	**280.00**	Postemergence
Clethodim	120.00	Postemergence
Clethodim	**90.00**	Postemergence
Cycloxydim	150.00	Postemergence
Cycloxydim	**112.00**	Postemergence
Bentazon	1680.00	Postemergence

Table 1 continued

Herbicide	Herbicides dose (g i.a.ha^{-1})[1]	Application time
Bentazon	**1260.00**	Postemergence
Ioxynil	675.00	Postemergence
Ioxynil	**506.00**	Postemergence
Nicosulfuron	80.00	Postemergence
Nicosulfuron	**60.00**	Postemergence
Rimsulfuron	10.00	Postemergence
Rimsulfuron	**7.50**	Postemergence
Tribenuron methyl	15.00	Postemergence
Tribenuron methyl	**11.25**	Postemergence
Paraquat	600.00	Postemergence
Paraquat	**450.00**	Postemergence
Dicamba + Triasulfuron	115.00	Postemergence
Dicamba + Triasulfuron	**87.00**	Postemergence
Dicamba + Tritosulfuron	150.00	Postemergence
Dicamba + Tritosulfuron	**112.00**	Postemergence
Foramsulfuron	562.00	Postemergence
Foramsulfuron	**420.00**	Postemergence
Control	-	Postemergence

1. Herbicides dose was determined according to the recommended rate for other crops and reduced doses were 75% of the recommended dose.
2. Reduced doses are shown in boldface.

Table 2 Some characteristics of herbicides used in the experiment.

Technical name	Trade name	Formulation	Active ingredient (%)	Mode of action	Manufacturer
Trifluralin	Treflan	EC	48.0	Cell division inhibitor	Gyah Company
Pendimethalin	Stomp	EC	30.0	Cell division inhibitor	Ariashimi Company
Metribuzin	Sencor	WP	70.0	Photosystem II inhibitor	Gyah Company
Bentazon	Basagran	SL	48.0	Photosystem II inhibitor	Ghazalshimi
Ioxynil	Totril	EC	22.5	Photosystem II inhibitor	Ariashimi Company
Oxadiazon	Ronstar	EC	25.0	Protoporphyrinogen oxidase inhibitor (PPO)	Gyah Company
Oxyfluorfen	Goal	EC	24.0	Protoporphyrinogen oxidase inhibitor (PPO)	Ariashimi Company
Haloxyfop-r-methyl	Gallant Super	EC	10.8	ACCase Inhibitor	Gyah Company
Sethoxydim	Nabu-S	EC	12.5	ACCase Inhibitor	Gyah Company
Clethodim	Select Super	EC	12.0	ACCase Inhibitor	Arysta Life Science Company of France
Cycloxydim	Focus	EC	10.0	ACCase Inhibitor	BASF Germany Company
Nicosulfuron	Cruise	SC	4.0	ALS inhibitor	Gyah Company
Rimsulfuron	Titus	DF	25.0	ALS inhibitor	Dupont Company
Tribenuron methyl	Granstar	DF	75.0	ALS inhibitor	Ariashimi Company
Foramsulfuron	Equip	OD	22.5	ALS inhibitor	Bayer Company
Paraquat	Gramoxone	SL	20.0	Photosystem I inhibitor	Ariashimi Company
Dicamba + triasulfuron	Lenotre	WG	70.0		Syngenta Company
Dicamba + tritosulfuron	Arrat	Combi-pack solid/liquid (KK)	25.0 % tritosulfuron + 50.0 % dicamba		BASF Germany Company

ACCase: Acetyl CoA Carboxylase, ALS: Acetolactate synthase.

Herbicide phytotoxicity on saffron plants was determined 45 days after crust crushing for PRE herbicides and 7, 14, 28 and 42 days after spraying for post herbicides, they were then ranked using European Weed Research Council (EWRC) scale ranging from 1 (no injury to the crop) to 9 (death of the plants) (Sandral *et al.,* 1997) (Table 3). In order to avoid the effect of weeds on saffron, weeds were removed throughout the growing season in all treatments. On 4th and 5th June 2017, five saffron plants were removed from each plot and growth characteristics including the number of replacement corms per plant and the total dry weight of corms were measured. In the second year, saffron flowers were manually picked daily from 25th of October to 15th of November 2017 and flower number and dried stigma yield were recorded. Stigmas were dried in an oven at 30 °C for 24 h to a constant weight before weighing (Koocheki *et al.,* 2013).

Table 3 Visual rating of injury caused by herbicides to weeds and crop based on EWRC scale.

Crop tolerance	Damage (%)	Evaluation score
No damage	0 - 1.0	1
Very little damage	1.0 - 2.5	2
More damage	2.5 - 7.0	3
Moderate and reversible damage	7.0 - 12.5	4
Moderate and consistent damage	12.5 - 20.0	5
Severe damage	20.0 - 30.0	6
Very severe damage	30.0 - 50.0	7
Nearly full kill	50.0 - 99.0	8
Full kill	99.0 - 100	9

Before data analysis, collected data were tested for normality and homogeneity of variances, using Kolmogorov-Smirnov test (SPSS 25). Analysis of variance (ANOVA) and Duncan's multiple range test (DMRT) were performed at 5% probability using SAS 9.3 software. Orthogonal comparisons were also used to compare herbicide groups effects at recommended and reduced doses.

Results

Herbicides phytotoxicity

Pre emergence herbicides treatments had very low phytotoxicity levels, which is characterized by a mild chlorosis in few plants (no injury). Therefore, their rating was disregarded based on EWRC rating system. In contrast, post emergence treatments showed higher levels of injuries ranging between 1 (slightly yellowing) and 8 (severe foliar chlorosis and necrosis), which indicated that the application of post emergence herbicides was responsible for the observed symptoms (Table 4). These effects included stunted plant growth, foliar chlorosis and necrosis and leaf tip chlorosis. Seven days after post herbicides spraying (DAS), the application of paraquat, oxyfluorfen, oxadiazon, ioxynil and bentazon respectively caused more injury compared to the other herbicides, (Table 4).

With regards to saffron phytotoxicity, a slight leaf chlorosis was observed in plants 7 DAS in treated plants with Acetyl CoA Carboxylase (ACCase) inhibitors including haloxyfop-r-methyl, sethoxydim, clethodim and cycloxydim and also metribuzin (Table 4). 14 DAS, treatments with acetolactate synthase (ALS) inhibitor herbicides showed more severe symptoms and the damages Continued until the end of the season (Table 4). An important point to highlight the use of ALS inhibitors is the fact that the injuries on the aerial parts of the plants were visible only after the second week of spraying, and increased from the third week on (Table 4).

Yield and yield components

Flower number and flower weight

There was a significant difference among the treatments in flower number and flower weight ($P < 0.01$) (Table 5). The highest and the lowest flower number and flower weight were obtained in control treatment and application of tribenuron methyl herbicide at recommended and reduced doses respectively. After tribenuron methyl, the application of nicosulfuron, dicamba + triasulfuron and foramsulfuron, rimsulfuron caused a significant reduction in the flower number and flower weight. Also contact herbicides such as ioxynil, bentazon, paraquat, oxyloflurfene and oxadiazone injured saffron significantly. In which, caused less injury to saffron compared to sulfonylurea herbicides such as tribenuron methyl. Pre emergence application of herbicides caused a significant reduction in the number and weight of saffron flowers. Among pre emergence herbicides, the highest and the lowest number of flowers were recorded in pendimethalin and trifluralin treatments respectively (Table 5). There were no significant differences between control treatment and post-emergence application of haloxyfop-r-methyl and cycloxydim at recommended and reduced doses and clethodim, sethoxydim, metribuzin and oxadiazon in reduced doses (Table 5). According to the results, increasing rimsulfuron dose from 7.5 to 10 g ai. ha^{-1} and also dicamba + tritosulfuron from 112 to 150 g ai. ha^{-1} caused a significant reduction in flower number and flower weight. Nonetheless, there was no significant difference between recommended and reduced doses of the other herbicides (Table 5).

Dried stigma yield

The effects of herbicides on stigma yield, were significant ($p < 0.01$) (Table 5). The highest stigma dry weight (0.54 g. m-2) belonged to control treatment, while among herbicide treatments the highest yields were recorded in post emergence application of haloxyfop-r-methyl and cycloxydim at recommended and reduced doses and the application of metribuzin, clethodim, sethoxydim and

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oxadiazon at reduced doses. (Table 5). The lowest dried stigma yield were recorded from plots under post emergence application of tribenuron methyl, nicosulfuron, dicamba + triasulfuron, foramsulfuron, rimsulfuron and dicamba + tritosulfuron respectively, which revealed that these herbicides have a high potential to damage saffron (Table 5).

Table 4 Visual rating of injury caused to saffron after herbicide applications based on EWRC scale.

Treatments	Herbicides dose (g ai.ha^{-1})[1]	Phytointoxication (EWRC scale – Notes 1- 9)[2]			
		7 DAS[3]	14 DAS	28 DAS	42 DAS
Control	-	1	1	1	1
Clethodim	**90.00**	1	1	1	1
Haloxyfop-r-methyl	**120.00**	1	1	1	1
Haloxyfop-r-methyl	162.00	1	2	1	1
Metribuzin	**395.00**	1	1	2	1
Sethoxydim	**280.00**	1	2	1	1
Clethodim	120.00	1	2	2	1
Cycloxydim	**112.00**	1	2	1	1
Metribuzin	525.00	1	2	2	2
Sethoxydim	375.00	1	2	1	1
Cycloxydim	150.00	2	2	2	1
Dicamba + Triasulfuron	**87.00**	2	3	4	4
Dicamba + Tritosulfuron	**112.00**	2	3	3	4
Foramsulfuron	**420.00**	2	3	4	5
Ioxynil	**506.00**	2	3	3	2
Rimsulfuron	**7.50**	2	3	4	5
Dicamba + Triasulfuron	115.00	2	3	5	5
Dicamba + Tritosulfuron	150.00	2	3	5	6
Foramsulfuron	562.00	2	3	4	6
Nicosulfuron	**60.00**	2	3	4	5
Nicosulfuron	80.00	2	3	5	6
Rimsulfuron	10.00	2	3	5	6
Tribenuron methyl	11.25	2	3	4	6
Oxadiazon	375.00	2	3	4	3
Tribenuron methyl	15.00	2	3	4	6
Bentazon	1440.00	3	3	3	2
Bentazon	**1260.00**	3	4	4	3
Ioxynil	675.00	3	4	4	3
Oxadiazon	500.00	3	4	5	4
Oxyfluorfen	**505.00**	4	5	5	4
Oxyfluorfen	720.00	5	6	6	4
Paraquat	**450.00**	7	7	6	5
Paraquat	600.00	8	7	7	6

1. Bold font is used to designate reduced doses.
2. European Weed Research Council (EWRC).
3. DAS: days after spraying.

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Table 5 Mean comparison of saffron traits in different herbicide treatments.

Treatment [1]	Mode	Herbicides dose (g ai.ha^{-1})[2]	Flower number (m^{-2})	Flower fresh weight (g.m^{-2})	dried stigma yield (g. m^{-2})	Number of replacement corm per clone	Total dry weight of corms (g.plant^{-1})
Control	-	-	119.00 a	48.00 a	0.54 a	8.90 a	27.93 a
HALO	post	**120.00**	117.00 ab	47.88 a	0.53 ab	8.80 a	27.46 ab
HALO	post	162.00	115.30 ab	45.37 ab	0.51 a-c	8.63 ab	26.56 a-c
CYCL	post	**112.00**	115.00 ab	44.10 a-c	0.49 a-d	8.60 ab	26.56 a-d
CLETH	post	**90.00**	114.67 a-c	44.36 a-c	0.49 a-d	8.60 ab	27.00 a-c
METR	post	**395.00**	113.33 a-d	44.15 a-c	0.49 a-d	8.43 a-c	26.23 a-e
CYCL	post	150.00	111.67 a-e	42.80 k-c	0.48 a-e	8.36 a-c	25.83 a-f
SETH	post	**280.00**	111.33 a-e	42.60 a-e	0.48 a-e	3.36 a-c	26.50 a-d
OXAD	post	**375.00**	109.67 a-f	42.43 a-e	0.47 a-e	8.23 a-d	25.53 a-g
METR	post	525.00	109.33 b-g	42.31 a-e	0.47 b-f	8.16 a-d	25.20 a-g
PEND	pre	1485.00	108.67 b-g	41.60 b-e	0.46 c-f	8.16 a-d	25.30 a-g
CLETH	post	120.00	105.67 b-h	40.48 b-f	0.45 c-g	7.80 a-f	24.36 b-i
SETH	post	375.00	104.30 b-h	40.10b-g	0.45 c-h	8.00 a-e	24.86 a-h
METR	pre	700.00	104.30 b-h	39.40 b-f	0.453 c-h	7.80 a-f	23.86 c-k
OXYF	post	**505.00**	102.30 b-i	38.90 c-h	0.43 d-j	7.63 b-f	23.46 d-k
OXAD	post	500.00	100.00 c-i	38.68 c-h	0.43 d-j	7.46 c-g	23.16 d-k
OXYF	post	720.00	99.00 d-j	37.64 d-h	0.41 f-j	7.43 c-g	22.76 e-k
TRIF + METR	pre	960.00 + 350.00	97.67 e-j	37.74 d-h	0.42 e-j	7.30 c-g	22.46 f-k
TRIF	pre	1200.00	95.30 f-j	36.56 g-j	0.41 f-j	7.13 e-h	22.26 g-l
BENT	post	**1260.00**	94.00 g-j	35.19 g-j	0.39 g-k	7.03 e-h	21.70 h-l
RIM	post	**7.50**	92.00 h-k	34.95 g-j	0.39 g-k	6.90 e-h	21.60 h-l
IOXY	post	**506.00**	92.00 h-k	34.61 g-j	0.39 g-k	6.90 e-h	21.30 i-l
OXAD	pre	500.00	91.67 h-k	33.30 h-j	0.37 j-l	6.86 e-h	21.43 h-l
DICA + TRIT	post	**112.00**	91.67 h-k	34.21 g-j	0.38 i-l	6.86 e-h	21.63 h-l
PARA	post	**450.00**	91.00 h-k	33.10 h-j	0.37 j-l	6.86 e-h	21.40 h-l
BENT	post	1680.00	88.67 i-k	30.15 i-k	0.34 k-m	6.73 f-h	20.80 j-l
IOXY	post	675.00	85.30 jk	28.75 k	0.32 lm	6.46 gh	19.96 kl
PARA	post	600.00	78.00 k	26.25 k	0.29 m	6.06 h	18.96 l
DICA + TRIT	post	150.00	60 1.00l	19.81 l	0.22 n	4.43 i	14.10 m
RIM	post	10.00	58.67 l	15.12 l	0.21 n	4.36 i	13.63 m
FORAM	post	**420.00**	50 1.00l	16.37 l	0.17 n	3.80 i	11.90 m
FORAM	post	560.00	46.67 l	15.12 l	0.18 n	3.76 i	11.73 m
DICA + TRIA	post	**87.00**	26.67 l	8.65 m	0.097 o	1.96 j	6.20 n
NICO	post	**60.00**	25.30 m	8.22 m	0.09 o	1.90 j	6.13 n
DICA + TRIA	post	115.00	22.00 m	7.04 m	0.08 o	1.75 j	5.60 n
NICO	post	80.00	15.00 mn	4.70 mn	0.05 op	1.33 j	3.86 n
TRI	post	**11.25**	2.30 n	0.72 n	0.01 p	0.26 k	0.80 o
TRI	post	15.00	1.00 n	0.31 n	0.00p	0.10 k	0.30 o
ANOVA	df		Mean square				
Replication	2		269.93^{*}	30.58^{ns}	0.00^{*}	1.66^{*}	17.01^{**}
Treatment	37		3653.20^{**}	626.62^{**}	0.06^{**}	20.07^{**}	192.46^{**}
Error	74		60.25	9.86	0.00	0.33	3.22
CV (%)	2		9.31	10.25	9.87	9.70	9.21

1. Abbreviation: TRIF, Trifluralin; PEND, Pendimethalin; METR, Metribuzin; OXAD, Oxadiazon; OXYF, Oxyfluorfen; HALO, Haloxyfop-r-methyl; SETH, Sethoxydim; CLETH, Clethodim; CYCL, Cycloxydim; BENT, Bentazon; IOXY, Ioxynil; NICO, Nicosulfuron; RIM, Rimsulfuron; TRI, Tribenuron methyl; PARA, Paraquat; DICA, Dicamba; TRIA, Triasulfuron; TRIT, Tritosulfuron; FORAM, Foramsulfuron.

2. Bold font is used to designate reduced doses.

In each column means with same letter according to Duncan's test are not significantly different at 5% level of probability.

ns, * and ** represent non-significant, significant at 5% and 1% probability level, respectively.

It seems that ALS inhibitor herbicides cannot be applied in saffron fields even at reduced doses. Orthogonal comparisons revealed that flower number and dried stigma yield, were significantly decreased in the treatments including ALS inhibitor herbicides compared to the other herbicide treatments (Table 6). Although ALS inhibitor herbicides showed less phytotoxicity symptoms, compared to paraquat herbicide, the translocation of these herbicides to corms caused a significant decrease in corms weight and dried stigma yield (table 6).

Number and weight of replacement corms

Results showed that there was significant difference between treatments in the number of corms and total dry weight of corms ($P < 0.01$) (Table 5). The highest number of replacement corm per clone (8.9) and total dry weight of corms (27.93 g) was observed in control treatment with no significant difference with pendimethalin, haloxyfop-r-methyl, sethoxydim, metribuzin, and cycloxydim at recommended and reduced doses and clethodim, oxyfluorfen and oxadiazon at reduced doses. On the other hand, the lowest number of corms and total dry weight of corms was observed in plots that were treated with tribenuron methyl herbicide at recommended and reduced doses (Table 5).

Orthogonal comparison

In general, orthogonal comparison showed that by reducing the herbicides dose, their injury to saffron was reduced. post emergence herbicides at recommended and reduced doses, reduced saffron flower yield (flower number and dried stigma yield) and total dry weight of corms significantly ($p \leq 0.01$). ALS inhibitor herbicides decreased flower number, dried stigma yield and total dry weight of corms significantly compared to ACCase inhibitor herbicides. Among herbicides, ALS inhibitor herbicides were the most harmful. (Table 6).

Table 6 Orthogonal comparison of the effect of treatments on the number of saffron flowers, dried stigma yield, total dry weight of corms.

Contrasts	Flowers number (m^{-2})	Dried stigma yield ($g.\ m^{-2}$)	Total dry weight of corms ($g.plant^{-1}$)
Post-emergent herbicides in recommended rates vs. Post-emergent herbicides in reduced rates	75.04 vs. 84.33**	0.32 vs. 0.37**	17.60 vs. 19.70**
ACCase Inhibitor herbicides vs. ALL[1]	111.96 vs. 74.21**	0.49 vs. 0.32**	26.15 vs. 17.36**
ALS inhibitor herbicides vs. ALL[2]	36.37 vs. 95.10**	0.18 vs. 0.40**	8.75 vs. 22.16**
Paraquat vs. ALS inhibitor herbicides	84.50 vs. 36.37*	0.33 vs. 0.18**	20.18 vs. 8.75**

1. Comparison of the ACCase Inhibitor herbicides (Haloxyfop-r-methyl, Sethoxydim, Clethodim and Cycloxydim) to the average of all other herbicide treatments.
2. Comparison of the ALS inhibitor herbicides (Nicosulfuron, Rimsulfuron, Tribenuron methyl and Foramsulfuron) to the average of all other herbicide treatments.
* and ** represent significant at $P < 0.05$ and $P < 0.01$, respectively, based on orthogonal contrasts.

Discussion

Based on the results, saffron is sensitive to herbicides and herbicide options for this plant are limited. Among the applied herbicides paraquat, oxyfluorfen and oxadiazon, caused higher levels of phytotoxicity compared to other herbicides. Similar results were obtained by Abbasian *et al.* (2014) who reported that oxyflurfen injured saffron severely by chlorosis of the leaves. Other results showed that oxyfluorfen induced necrotic damages on saffron leaves, which were tolerable for the plant and bromoxynil and ioxinil had undesirable effects on saffron causing chlorosis and necrosis (Galavi and Sarrani, 2006). ACCase inhibitor herbicides caused the least injury, while ALS inhibitor herbicides damaged saffron severely. Abbasian *et al.* (2014) also reported similar results from the application of metribuzin+

haloxyfop-r-methyl herbicides. Undesirable effects of haloxyfop-r-methyl herbicide in the form of foliar chlorosis along with the early dieback of plant have been reported in previous studies (Amiri, 1990; Abbasi, 1996; Zare Hosseini *et al.*, 2014; Behravan *et al.,* 2016). Vafabakhsh (2001) reported that the application of atrazine, haloxyfop and metribuzin in saffron induced yellowing and early senescing of saffron leaves. But Galavi and Saaraani (2006) mentioned that metribuzin did not damage saffron and could successfully control weeds. Among pre emergence herbicides, the highest stigma yield was recorded in pendimethalin herbicide and also post emergence application of metribuzin, oxadiazone and oxyfluorfen caused greater dried stigma yield than the other post emergence herbicides. Other researchers have reported that trifluralin and ethalfluralin caused significant injury and yield loss of saffron (Norouzzadeh and Delghandi, 2006; Sadrabadi Haghighi and Ghanad Tosi, 2016). In contrast, some studies showed that pre emergence application of ethalfluralin has the least effect on saffron yield (Rahimian, 1993; Abbasi, 1996).

Conclusion

The lowest number of flowers and stigma dry weight were obtained in control treatment and post emergence application of tribenuron methyl herbicide respectively. Although, contact herbicides can cause severe phytotoxicity symptoms in saffron and reduce dried stigma yield, some of these herbicide types such as oxadiazone and oxyfluorfen have a high potential for application in saffron fields. Among pre emergence herbicides, the highest saffron yield was recorded in pendimethalin treatment,namely it had better performance compared to other pre emergence herbicides in saffron fields. Generally, our results showed that the post emergence herbicides of haloxyfop-r-methyl, sethoxydim, clethodim, cycloxydim, metribuzin, oxadiazon and oxyfluorfen and also pre-emergent herbicides of pendimethalin and metribuzin have high potential to be used in saffron fields. The application of herbicides in their reduced doses decreased their phytotoxicity significantly. Saffron phytotoxicity was lower in treated plants with ACCase inhibitors than the other herbicides.

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ارزیابی تحمل زعفران .*Crocus sativus* L به برخی از علف‌کش‌ها

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چکیده: کنترل علف‌های هرز در مزارع زعفران بسیار ضروری است، اما تاکنون هیچ علف‌کش اختصاصی جهت کنترل علف‌های هرز زعفران ثبت نشده است. این آزمایش در قالب طرح بلوک‌های کامل تصادفی با سه تکرار در طول سال‌های ۱۳۹۶-۱۳۹۵ انجام شد. تیمارها شامل کاربرد علف‌کش‌های: تریفلورالین، پندیمتالین، متریبوزین، آیوکسینیل، بنتازون، اگزادیازون، اکسی‌فلورفن، سیتوکسیدیم، هالوکسی فوپ آرمتیل، کلتودیم، سیکلوکسیدیم، نیکوسولفورون، ریم سولفورون، تری بنورون متیل، فورام سولفورون، پاراکوات، دای کامبا + تریاسولفورون، دای کامبا + تریتوسولفورون در مقادیر توصیه شده و کاهش یافته بود. ویژگی‌های زعفران شامل تعداد گل، وزن تر و خشک گل و کلاله، وزن خشک برگ، تعداد بنه‌ها و وزن کل بنه‌ها اندازه‌گیری شد. در اواخر شهریور ۱۳۹۵ بنه‌های مادری در فواصل ۱۰ × ۵ سانتی‌متر و عمق ۱۵ سانتی‌متر کشت شدند. نتایج نشان داد زمانی‌که از علف‌کش‌های پیش رویشی استفاده شدند علائم گیاه‌سوزی بر روی زعفران مشاهده نشد، اما کاربرد پس رویشی علف‌کش‌ها سطوح متفاوتی از گیاه‌سوزی از شدید تا خفیف را نشان داد. کاربرد پاراکوات، اکسی‌فلورفن و اگزادیازون به‌ترتیب سطوح بالاتری از گیاه‌سوزی در مقایسه با دیگر علف‌کش‌ها ایجاد کردند. براساس نتایج آزمایش، علف‌کش‌های بازدارنده استیل کوآنزیم آ کربوکسیلاز حداقل خسارت به زعفران را ایجاد کردند، درحالی‌که علف‌کش‌های بازدارنده ALS به‌شدت به زعفران خسارت وارد کردند. بیش‌ترین و کم‌ترین وزن خشک کلاله به‌ترتیب از تیمار شاهد (۰/۵۴ گرم بر متر مربع) و کاربرد پس رویشی تری‌بنورون متیل (۰/۰۰۳ گرم بر متر مربع) به‌دست آمد. در بین علف‌کش‌های پیش رویشی، بیش‌ترین وزن خشک کلاله با کاربرد علف‌کش پندیمتالین به‌دست آمد. هم‌چنین از کاربرد پس‌رویشی متری‌بوزین، اگزادیازون و اکسی‌فلورفن در مقایسه با دیگر علف‌کش‌های پهن‌برگ‌کش، وزن خشک کلاله بیش‌تری به‌دست آمد. زمانی که علف‌کش‌ها در مقادیر کاهش یافته استفاده شدند عملکرد افزایش و گیاه‌سوزی کاهش یافت. در بین علف‌کش‌های مورد بررسی، تریفلورالین، اکسی‌فلورفن، پندیمتالین و متری بوزین به‌عنوان علف‌کش‌های انتخابی در زعفران به‌کار برده شوند.

واژگان کلیدی: علف‌کش، عملکرد زعفران، کنترل شیمیایی، گیاه‌سوزی

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