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Research Article

Chemical weed management programs for cycloxydim-tolerant maize in Iran

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Abstract: In order to introduce new chemical weed management program in maize weed control in Iran, a study was conducted during 2014 and 2015. Experiment were carried out in a randomized complete block design with three replications. 15 treatments of the common maize herbicides, including nicosulfuron, foramsulforon, eradicane and 2,4-D + MCPA were applied in their recommended doses, moreover the treatments related to cycloxydim with dicamba + tritosulfuron were used with different doses and in different times along with two control treatments (weedy and weed-free). Treatments contained 75-150 g a.i. ha^{-1} of cycloxydim, showed similar results with the common treatments including nicosulfuron, foramsulforon, eradicane and 2,4-D + MCPA. However, treatments with high doses of cycloxydim, had a significant reduction in weed density and weed biomass. There were no significant differences between the effects of treatments on maize grain yield and biomass. Despite the acceptable weed control of the combined treatment of cycloxydim with dicamba plus tritosulfuron, maize canopy could overcome weed growth. Based on the results and by considering cycloxydim efficacy in controlling perennial grassy weeds in maize plantation, this chemical is a suitable option during different growing stages of weeds and maize. Finally, the application of 200-300 g a.i. ha^{-1} of cycloxydim combined with dicamba plus tritosulfuron was the best option from an economic and environmental safety points of view.

Keywords: maize, cycloxydim, herbicide tolerance, herbicide resistance

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Introduction

Maize stands out as the most produced crop in the world: in the season 2014-2015, world production was 1.008.79 billion tons (U S D A, 2015) and In Iran, it was 1.658.875 tons (Agriculture Statistics, 2015). In this regard, maize cultivation has economic, social and cultural relevance, besides its importance to the agricultural sector, which contributes to the food security of agricultural proprietaries, especially for small producers. Among yield-limiting factors in maize, weeds are one of the most significant ones (Mousavi, 2008; Anonymous, 2015; Galon *et al*., 2018).

In maize, the estimated yield losses due to weed competition are ≤ 80% if no control method is adopted (Rashed Mohasel *et al*., 2002; Carvalho *et al*., 2007). Therefore, weed control is one of the most important factors in maize cultivation. Despite the environmental

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and some management problems with herbicides, they remain one of the most popular and practical methods in weed control (Zargar *et al*., 2017). However, there are some broadleaf herbicides such as 2,4-D for maize weeds control, grassy selective herbicides (ACCase inhibitors) have not been registered yet. Some herbicides such as; alachlor, acetochlor and EPTC which are known as pre-emergence herbicides, do not usually have acceptable results during critical periods of weed control in maize fields. In addition, acetolactate synthetase (ALS) inhibiting herbicides which are commonly used in maize, limit crop rotation due to their soil bio-persistence such as foramsulfuron and nicosulfuron (Zand *et al*., 2013).

Although, some dual-purpose herbicides (grassy and broadleaf herbicides) could control some grassy weeds in maize fields, the problem remains unsolved (Zand *et al*., 2013). Therefore, the need for some other approaches to control them is highly desirable. Accordingly, it is possible to control weeds by developing crops tolerant to herbicides; including glyphosate and glufosinate-tolerant maize (Johnson *et al*., 2000; Cavalieri *et al*., 2008). Besides glyphosate and glufosinate-tolerant maize, cycloxydim tolerant maize (CTM) has made it possible to apply cycloxydim herbicide to improve weed control spectra. Cycloxydim controls grassy annual and perennial species also has a high flexibility in application, and could be combined with broadleaf herbicides in corn fields (Dotray *et al*., 1993; Tredaway *et al*., 1998). BASF Company, as the exclusive owner of CTM gene, has provided an innovative chemical weed control method by the use of cycloxydim tolerant maize (CTM). In this approach, cycloxydim is being used as a selective herbicide with an Arrat broadleaf herbicide which is a combination of dicamba plus tritosulfuron. Moreover, CTM has not only provided the possibility to use cycloxydim to control grassy weeds, but also it is considered safe both for rotational crops such as sugar beet, chickpea and canola and humans (Zand *et al*., 2013). It can be also easily combined and applied with several other broadleaf herbicides. This study was conducted to evaluate the efficacy of cycloxydim as a choice of chemical control of weeds in maize in Iran.

Materials and Methods

This study was carried out to evaluate chemical weed control in cycloxydim tolerant maize (CTM) at the Barakat Agro-Industrial Co., Jovein, (36°42″ N, 57°25″ E, and 1100 m a.s.l.), Khorasan-Razavi during 2014 and 2015, Iran. The field soil is classified as fine-loamy soil (50% sand, 12% clay and 38% silt, 0.75% organic matter) with a 7.6 pH and EC 1.4 dS m^{-1}. Jovein is located in a semi-arid region with an average rainfall of 253 mm and an average temperature of 13.5 °C. The experiments were conducted in a randomized complete block design with three replicates. The soil fertilization of the fields was performed regarding to soil characteristics, following the recommendations for maize cultivation (Ghaibi *et al*., 2014).

Treatments included different methods of maize weed control in 17 levels as indicated in table 1 and herbicides described in table 2. Maize was planted on 25 May 2014, and 27 May 2015, using a tractor-mounted drill at 27 kg seed ha^{-1} at 2-3 cm depth. Plots were harvested at the end of September for both experiments. Cycloxydim tolerant maize hybrid (ZP684CTM) was provided by Zemun polje Company-Serbia.

Plot dimensions were five corn rows wide, rows spaced 75 cm apart and 8 m long and the distance between plots and blocks were 1 and 1.5 meter respectively. Herbicides were applied using a calibrated lance sprayer (Matabi Super Agro 20 L sprayer, UK) fitted with an 8002 flat fan yellow nozzle tip delivering 210 L ha^{-1} at a pressure of 200 kPa.

In order to evaluate the effects of the treatments on weeds, sampling was carried out 15, 30 and 45 days after spraying, and one week before the maize harvesting on the three middle rows. In each sampling, the density of each weed species was separately counted within a quadrate of 0.375 m^{-2} (50 × 75 cm). Then, they were harvested at the stem base close to the soil surface and later oven-dried at 75 °C for 48 h and weighed. Maize grain yield and biomass were determined after harvesting at the end of the season in an area of one square meter. Treated and non-treated control plots were involved in each block of each experiment. In the treated control, no weeding was done whereas hand-weeding was done in the non-treated control until complete maize canopy.

Table 1 Experimental treatments, doses and their abbreviations.

No	Treatments	Timing	Dose (g ai ha^{-1})	Abbreviation
1	Weedy	—	—	WI
2	Nicosulfuron	3-4 Leaf	80	Nic80
3	Cycloxydim / (dicamba + tritosulfuron)	3-4 Leaf / 5-6 Leaf	75 / (100 + 50)	C75 + D100 T50
4	Cycloxydim / (dicamba + tritosulfuron)	3-4 Leaf / 5-6 Leaf	(150) / (100 + 50)	C150 + D100 T50
5	Cycloxydim / (dicamba + tritosulfuron)	3-4 Leaf / 5-6 Leaf	(300) / (100 + 50)	C300 + D100 T50
6	Cycloxydim / (dicamba + tritosulfuron)	3-4 Leaf / 5-6 Leaf	(450) / (100 + 50)	C450 + D100 T50
7	Cycloxydim / (dicamba + tritosulfuron)	3-4 Leaf & repeated 20 days later / 5-6 Leaf	(37.5 & 37.5) + (100 + 50)	C37.5 × 2 + D100 T50
8	Cycloxydim / (dicamba + tritosulfuron)	3-4 Leaf & repeated 20 days later / 5-6 Leaf	(75 & 75) + (100 + 50)	C75 × 2 + D100 T50
9	Cycloxydim / (dicamba + tritosulfuron)	3-4 Leaf & repeated 20 days later / 5-6 Leaf	(150 & 150) + (100 + 50)	C150 × 2 + D100 T50
10	Cycloxydim / (dicamba + tritosulfuron	3-4 Leaf & repeated 20 days later / 5-6 Leaf	(225 & 225) + (100 + 50)	C225 × 2 + D100 T50
11	Cycloxydim / (dicamba + tritosulfuron)	5-6 Leaf / 5-6 Leaf	(100) + (150 + 75)	C100 + D150 T75
12	Cycloxydim / (dicamba + tritosulfuron)	5-6 Leaf / 5-6 Leaf	(100) + (200 + 100)	C100 + D200 T100
13	Cycloxydim / (dicamba + tritosulfuron)	5-6 Leaf / 5-6 Leaf	(500) + (100 + 50)	C500 + D100 T50
14	EPTC / (2,4-D + MCPA)	Preemergence / 3-4 Leaf	(4100 + 1012)	E4100 + T1012
15	Foramsulfuron	3-4 Leaf	45	FS45
16	2,4-D + (MCPA / atrazine)	3-4 Leaf / 5-6 Leaf	(1012 + 1200)	2M 1020 + At 1200
17	Weed-free	—	—	WF

Table 2 Herbicides descriptions applied in the experiments.

Active ingredient	Trade name	Formulation	Mode of action
Nicosulfuron	Accent	SC 4%	ALS Inhibitor
Cycloxydim	Focus Ultra	EC 10%	Fatty Acid Synthesis Inhibitor
Dicamba + tritosulfuron	Arat	WDG (500 g kg^{-1} + 250 g kg^{-1})	Synthetic auxins
EPTC	Eradican	EC 82%	Lipid Synthesis Inhibitor
2,4-D + MCPA	U46 Combi	SC 67.5%	Synthetic auxins
Foramsulfuron	Equip	OD 22.5%	ALS Inhibitor
Atrazine	Azaprim	WP 80%	Photosystem II Inhibitor

Data analysis

Before analysis, collected data were tested for normality and homogeneity of variances. Data analysis of the compound variance was performed with SAS 9.1 software and the means were compared using the least significant difference (LSD) test at the P ≤ 0.05 level of significance.

Results

Results showed that nine weed species including *Amaranthus retroflexus* L, *Digitaria sanguinalis* L. Scop, *Convolvulus arvensis* L., *Echinochloa crus-galli* (L.) P. Beauv, *Setaria verticillate* (L.) P. Beauv, *Chenopodium album* L, *Portulaca oleracea* L. *ssp, Sorghum halepense* (L.) Pers and *Tribulus terrestris* L. were the dominant species on the experimental field. Among them, *Amaranthus retroflexus* L. and *Digitaria sanguinalis* L. Scop had the highest relative frequency 23% and 17% with more than 20% and 16% of all the weeds biomass respectively. During the first year, dominant broadleaf weeds *Amaranthus retroflexus* L. and *Convolvulus arvensis* L. were 63.5% of all weeds relative frequency and 61% of the weeds' biomass, while in the second year, grassy weed *Digitaria sanguinalis* L. Scop with the relative frequency of 66% and 64% of biomass was dominant. Besides mentioned species, some others such as; *Solanum nigrum* (L.), *Conyza Canadensis* (L.) *Cronquist, Glycyrrhiza glabra* (L.), *Sonchus asper* (L.) Hill, *Cynodon dactylon* (L.), *Cirsium arvense* (L.) Scop, *Hibiscus trionum* (L.), *Xanthium strumarium* (L.) and *Tragopogon dubius* Scop were observed with very low frequencies (Table 3).

According to the results, since the interactions of the effect of year and herbicide treatments were significant for the measured traits, the data analysis and the mean comparisons had to be carried out annually and separately. During the first year, 15 days after spraying, treatments 5 (C300 + D100T50), 9 (C150 × 2 + D100T50) and 12 (C100 + D200T100), were the best for reducing weed dry weight and weed density. However, no significant difference was observed between them and the other treatments in which dicamba + tritosulfuron applied with cycloxydim herbicide and foramsuforun treatment (Table 4).

Similar results were obtained in the second year in which the lowest weeds density was attained in treatments 5 (C300 + D100T50), 10 (C225 × 2 + D100T50) and 11 (C100 + D150 T75). The lowest weed dry weight was achieved for treatments 5, 10 and 13 in which no significant difference was observed between these treatments and treatments including dicamba + tritosulfuron with cycloxydim herbicide 15 days after spraying. The highest density and dry weight of weeds was for treatments 2 (Nic80), 14 (E4100 + T1012), 15 (FS45) and 16 (2M 1020 + At 1200) which were not significantly different with treatment 7 (C37.5 × 2 + D100 T50) in both years. In most all cases, treatment 7 (C37.5 × 2 + D100T50) had the lowest weed control efficacy (Tables 4 and 5). Although broadleaf and grassy weeds had quite different frequency in both years, the results obtained from the effects of cycloxydim + dicamba + tritosulfuron were similar for both years. It indicates that the application of these treatments, has led to an acceptable weed control in various conditions of weeds flora.

During the first year, no significant difference was found between treatment 16 (2M 1020 + At 1200) and treatments which included cycloxydim with dicamba + tritosulfuron for weed density and weed biomass. Since the broadleaf weeds had the absolute dominance during the first year, the application of 2,4-D + MCPA and atrazine could satisfactorily control them (Table 4).

Similar results were indicated 30 days after spraying in which treatments 5 (C300 + D100T50), 6 (C450 + D100T50) and 12 (C100 + D200T100) were the most efficient for weed control. However they had no significant difference with weed-free control and other treatments which cycloxydim was applied plus dicamba + tritosulfuron and also treatment 14 (E4100 + T1012), 15 (FS45) and 16 (2M 1020 + At 1200).

Table 3 Characteristics of weeds population weedy treatment at the end of the growing season.

Scientific name	Family name	Life Cycle	2014 Density (plant m^{-2})	2014 Biomass (g m^{-2})	2014 Relative frequency (%)	2014 Biomass (%)	2015 Density (plant m^{-2})	2015 Biomass (g m^{-2})	2015 Relative frequency (%)	2015 Biomass (%)
Digitaria sanguinalis (L.) Scop.	Poaceae	Annual	17.78	92.77	10.58	11.13	55.11	184.12	36.9	34.56
Amaranthus retroflexus L.	Amaranthaceae	Annual	46.22	188.02	27.51	22.55	8.89	32.87	5.95	6.17
Convolvulus arvensis L.	Convulvulaceae	Perennial	23.11	134.16	13.76	16.09	19.56	70.8	13.1	13.29
Echinochloa crus-galli (L.) P. Beauv.	Poaceae	Annual	11.56	70.17	6.88	8.42	20.44	70.59	13.69	13.25
Setaria verticillata (L.) P. Beauv.	Poaceae	Annual	12.44	66.6	7.41	7.99	14.22	50.46	9.52	9.47
Chenopodium album L.	Chenopodiaceae	Annual	13.33	79.16	7.94	9.49	5.33	19.72	3.57	3.7
Tribulus terrestris L.	Zygophyllaceae	Annual	7.11	41	4.23	4.92	6.22	24.03	4.17	4.51
Portulaca oleracea L. ssp.	Protulacaceae	Annual	8	44.84	4.76	5.38	2.67	12.95	1.79	2.43
Solanum nigrum L.	Solanaceae	Perennial	8.89	28.13	5.29	3.37	4.44	16.35	2.98	3.07
Sorghum halepense (L.) Pers.	Poaceae	Perennial	8	38.28	4.76	4.59	0.89	4.19	0.6	0.79
Cynodon dactylon L.	Poaceae	Perennial	4.44	16.51	2.65	1.98	1.78	6.65	1.19	1.25
Xanthium strumarium L.	Asteraceae	Annual	2.67	14.88	1.59	1.78	0.89	3.72	0.6	0.7
Cirsium arvense (L.) Scop.	Asteraceae	Perennial	0.89	4.34	0.53	0.52	1.78	8.11	1.19	1.52
Glycyrrhiza glabra L.	Fabaceae	Perennial	1.78	6.62	1.06	0.79	0.89	4.63	0.6	0.87
Hibiscus trionum L.	Malvaceae	Annual	0.89	2.77	0.53	0.33	2.67	7.68	1.79	1.44
Conyza canadensis (L.) Cronquist	Asteraceae	Annual	0.89	5.53	0.53	0.66	0.89	4.06	0.6	0.76
Sonchus asper (L.) Hill	Asteraceae	Biennial	0	0	0	0	1.78	8.78	1.19	1.65
Tragopogon dubius Scop.	Asteraceae	Annual	0	0	0	0	0.89	3.06	0.6	0.57
Total	—	—	168	833.79	100	100	149.33	532.76	100	100

Table 4 Mean Comparison the effect of treatments on maize weed density and weed biomass 15 and 30 days after spraying

No	Treatments	Density (plant m^{-2})				Biomass (g m^{-2})			
		15 (DAS)		30 (DAS)		15 (DAS)		30 (DAS)	
		2014	2015	2014	2015	2014	2015	2014	2015
1	WI	97.78^{a¶}	164.40^{a}	200.70^{a}	116.70^{a}	100.40^{a}	181.30^{a}	388.30^{a}	369.60^{a}
2	Nic80	41.78^{b}	83.55^{b}	57.20^{b}	53.64^{b}	66.66^{b}	87.11^{de}	138.60^{c}	163.20^{c}
3	C75 + D100T50	21.33^{cde}	19.55^{ef}	19.12^{de}	1.79^{d}	46.22^{c}	32.00^{gh}	95.91^{cdef}	19.84^{e}
4	C150 + D100T50	12.44^{def}	16.00^{ef}	11.95^{de}	2.25^{d}	29.33^{cde}	28.45^{gh}	46.7^{fgh}	41.46^{e}
5	C300 + D100T50	7.11^{ef}	8.00^{ef}	5.057^{e}	1.44^{d}	17.78^{ef}	9.77^{hi}	71.46^{defg}	6.73^{e}
6	C450 + D100T50	13.33^{def}	12.45^{ef}	5.973^{e}	6.59^{d}	13.33^{ef}	5.33^{hi}	18.28^{gh}	3.617^{e}
7	C37.5 × 2 + D100T50	17.78^{cdef}	81.78^{b}	22.3^{de}	34.15^{c}	64.00^{b}	93.33^{cd}	249^{b}	205.6^{b}
8	C75 × 2 + D100T50	10.67^{def}	51.55^{cd}	8.29^{e}	8.39^{d}	32.89^{cde}	44.45^{fg}	91.29^{cdef}	81.87^{d}
9	C150 × 2 + D100T50	7.11^{ef}	16.01^{ef}	4.66^{e}	3.827^{d}	26.66^{cde}	29.34^{gh}	60.3^{efg}	11.81^{e}
10	C225 × 2 + D100T50	21.33^{cde}	8.89^{ef}	18.71^{de}	1.07^{d}	26.67^{cde}	7.11^{hi}	70.66^{defg}	4.93^{e}
11	C100 + D150T75	12.44^{def}	13.33^{ef}	7.147^{e}	3.78^{d}	20.45^{de}	28.45^{gh}	82.04^{def}	40.43^{e}
12	C100 + D200T100	8.00^{ef}	32.89^{de}	2.79^{e}	10.32^{d}	15.12^{ef}	31.11^{gh}	23.39^{gh}	41.32^{e}
13	C500 + D100T50	10.67^{def}	18.67^{ef}	6.29^{e}	2.66^{d}	22.23^{de}	10.67^{hi}	65.26^{efg}	4.03^{e}
14	E4100 + T1012	33.78^{bc}	89.78^{b}	34.05^{cd}	29.54^{c}	32.89^{cde}	116.4^{bc}	91.18^{cdef}	143.60^{c}
15	FS45	19.56^{cde}	79.11^{b}	21.10^{de}	69.75^{b}	30.23^{cde}	123.6^{b}	124.1^{cd}	206.30^{b}
16	2M 1020 + At 1200	28.45^{bcd}	73.78^{bc}	43.66^{bc}	56.19^{b}	39.12^{cd}	67.55^{ef}	110.60^{cde}	126.90^{c}
17	WF	0.00^{f}	0.00^{f}	0.00^{e}	0.00^{d}	0.00^{f}	0.00^{i}	0^{i}	0^{f}

Means followed by the same letters in each column are not significantly different (LSD test, $P \leq 0.05$).

DAS: Days after spraying, **C:** Cycloxidim; **DT:** dicamba + tritosulfuron; × **2:** 50% of herbicides applied in the 3-4 maize leaf stage and 50% of herbicides applied 20 days after; **E:** EPTC; **FS:** foramsulfuron; **2M:** 2.4-D + MCPA; **At:** atrazine; **Nic:** nicosulfuron; **WI:** weedy and **WF:** weed free.

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Table 5 Mean comparison the effect of treatments on weed density and weed biomass 45 days after spraying and one week before harvest.

Treatment No.	Treatments	Density (Plant.m^{-2})				Biomass (g.m^{-2})			
		45 (DAS)		One week before harvesting		45 (DAS)		One week before harvesting	
		2014	2015	2014	2015	2014	2015	2014	2015
1	WI	70.22^{b¶}	143.10^{a}	706.40^{a}	478.80^{a}	197.30^{a}	160.90^{a}	996.40^{a}	576.50^{a}
2	Nic80	70.22^{b}	98.66^{b}	196.30^{c}	213.40^{c}	64.89^{b}	64.89^{b}	296.60^{d}	343.50^{b}
3	C75 + D100T50	51.56^{c}	29.33^{de}	174.70^{cd}	108.80^{de}	67.55^{b}	23.11^{defg}	473.70^{c}	180.20^{c}
4	C150 + D100T50	23.11^{ef}	28.44^{de}	50.95^{efg}	80.89^{ef}	17.78^{cde}	16.00^{efgh}	114.90^{fghi}	77.39^{de}
5	C300 + D100T50	16.89^{ef}	16.89^{de}	86.2^{defg}	54.56^{efg}	20.45^{cd}	6.22^{fgh}	165.70^{defgh}	37.84^{de}
6	C450 + D100T50	11.56^{fg}	17.78^{de}	25.12^{fg}	40.77^{fg}	8.00^{de}	4.447^{gh}	45.50^{hi}	19.32^{e}
7	C37.5 × 2 + D100T50	88.01^{a}	82.67^{bc}	347.70^{b}	329.20^{b}	67.56^{b}	72.89^{c}	618.40^{b}	384.30^{b}
8	C75 × 2 + D100T50	44.44^{c}	43.56^{cde}	130.20^{cde}	142.80^{d}	23.12^{cd}	8.89^{fgh}	209.20^{defg}	61.22^{de}
9	C150 × 2 + D100T50	23.12^{ef}	12.45^{de}	82.84^{defg}	39.27^{fg}	17.78^{cde}	8.00^{fgh}	146.50^{efgh}	23.23^{e}
10	C225 × 2 + D100T50	25.78^{def}	8.887^{de}	83.66^{defg}	36.16^{fg}	17.78^{cde}	32.00^{de}	152.70^{efgh}	36.75^{de}
11	C100 + D150T75	23.11^{ef}	47.11^{cde}	108.5^{cdef}	139.00^{d}	24.00^{cd}	14.22^{efgh}	194.50^{defg}	182.00^{c}
12	C100 + D200T100	20.45^{ef}	38.23^{cde}	41.76^{efg}	140.60^{d}	9.77^{de}	9.78^{fgh}	87.58^{ghi}	117.00^{cd}
13	C500 + D100T50	30.23^{de}	16.89^{de}	70.50^{efg}	64.40^{ef}	17.78^{cde}	6.22^{fgh}	164.00^{defgh}	73.75^{de}
14	E4100 + T1012	37.33^{cd}	56.89^{bcd}	124.10^{cde}	199.70^{c}	21.34^{cd}	8.00^{fgh}	206.00^{defg}	314.80^{b}
15	FS45	39.10^{cd}	47.11^{cde}	192.90^{c}	212.80^{c}	31.11^{c}	31.11^{de}	285.10^{de}	383.90^{b}
16	2M 1020 + At 1200	46.22^{c}	47.11^{cde}	174.10^{cd}	158.20^{cd}	31.11^{c}	25.78^{def}	254.20^{def}	298.90^{b}
17	WF	0.00^{g}	0.00^{f}	0.00^{h}	0.00^{h}	0.00^{f}	0.00^{fg}	0.00^{h}	0.00^{f}

Means followed by the same letters in each column are not significantly different (LSD test, $P \leq 0.05$.

C: Cycloxidim; **DT:** dicamba + tritosulfuron; **×2:** 50% of herbicides applied in the 3-4 maize leaf stage and 50% of herbicides applied 20 days after; **E:** EPTC; **FS:** foramsulfuron; **2M:** 2.4-D + MCPA; **At:** atrazine; **Nic:** nicosulfuron; **WI:** weedy and **WF:** weed free.

Similar results were observed regarding weed biomass during the first year (Table 4), but in the second year there were some differences among the treatments. The lowest weed density and weed biomass was attained in treatments 5 (C300 + D100T50), 6 (C450 + D100T50), 10 (C225 × 2 + D100T50) and 13 (C500 + D100T50) which had no statistical difference with other cycloxydim application treatments + dicamba + tritosulfuron. However, they had a significant difference with common treatments used in the region including; treatments of 2 (Nic80), 14 (E4100 + T1012), 15 (FS45) and also weed free control treatment (WF).

In general, no significant difference was observed in weed density in weedy treatment after 15 and 30 days of spraying, however 45 days after spraying, weed density decreased significantly. Nevertheless, since then and till one week before maize harvesting, weed density increased significantly during both years (Tables 4 and 5). It is perhaps because of the emergence of new flashes of weeds and their emerging patterns. According to weed flora and relative frequency of the weeds, during the first year, 45 days after spraying the effects of treatments on weed density had similar results with 15 days after spraying. However, in the second year the lowest weed density was observed in treatments with cycloxydim plus dicamba + tritosulfuron, especially those above 150 g ai. ha^{-1} of cycloxydim. It appears that the dominance of grassy weeds during the second year and the efficacy spectrum of the mentioned herbicide treatments were of importance here. Similar results were obtained for weed dry weight during both years (Table 5).

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The lowest grain yield and maize biomass was observed in weedy treatment and next in the treatments with lowest efficacy in weed control including; 14 (E4100 + T1012), 15 (FS45) and 16 (2M 1020 + At 1200) treatments, compared to cycloxydim applied treatments. There were no significant differences in the treatments where cycloxydim with dicamba + tritosulfuron were applied (Table 6).

Table 6 Mean Comparison the effect of treatments on maize grain yield and biomass.

Treatment No.	Treatment	Biological yield (t ha^{-1})	Seed yield (t ha^{-1})
1	WI	3.30	0.89^{a}
2	Nic80	57.20^{b}	53.64^{b}
3	C75 + D100T50	19.12^{de}	1.79^{d}
4	C150 + D100T50	11.95^{de}	2.25^{d}
5	C300 + D100T50	5.05^{e}	1.44^{d}
6	C450 + D100T50	5.97^{e}	6.58^{d}
7	C37.5 × 2 + D100T50	22.30^{de}	34.15^{c}
8	C75 × 2 + D100T50	8.29^{e}	8.39^{d}
9	C150 × 2 + D100T50	4.66^{e}	3.83^{d}
10	C225 × 2 + D100T50	18.71^{de}	1.07^{d}
11	C100 + D150T75	7.14^{e}	3.78^{d}
12	C100 + D200T100	2.79^{e}	10.32^{d}
13	C500 + D100T50	6.29^{e}	2.66^{d}
14	E4100 + T1012	34.05^{cd}	29.54^{c}
15	FS45	21.10^{de}	69.75^{b}
16	2M 1020 + At 1200	43.66^{bc}	56.19^{b}
17	WF	200.70^{e}	116.70^{f}

Means followed by the same letters in each column are not significantly different (LSD test, $P \leq 0.05$).

Discussions

Based on the results of this experiment, applying cycloxydim herbicide along with Arrat broadleaf weed killer has a favorable efficacy in controlling grassy and broadleaf weeds which has also been reported in some similar researches (Simic *et al*., 2013; Vancetovic *et al*., 2011). In a study, the performance of CTM in broadleaf weed control was evaluated under nine treatments; including the application of cycloxydim alone or in combination with postemergence herbicides (mesotrione and tembotrione). It was observed that combined treatment of cycloxydim at 200 g a.i. ha^{-1} plus tembotrione at 88 g a.i. ha^{-1}, had the highest efficacy for weed control (Simic *et al*., 2013), which are consistent with the results of our study. It can be concluded that in all cases, treatments containing 75-100 g a.i. ha^{-1} of cycloxydim had similar results with the common ongoing treatments in the region. Those treatments which have used higher doses of cycloxydim plus the application of dicamba + tritosulfuron caused a significant reduction in weed density and weed dry weight compared to the common ones applied in the region, which in most cases acted as an equivalent to full season weeding treatment.

Our results are in agreement with other studies regarding the fact that the application of cycloxydim with a broadleaf herbicide leads to an adequate CTM weed control (Vancetovic *et al*., 2011; Kukorelli *et al*., 2012; Simic *et al*., 2013). Landes *et al*. (1996) also reported that the application of 100-200 g a.i. ha^{-1} of cycloxydim had resulted in a desirable weed control. Simic *et al.* (2013) stated similar results by using cycloxydim with broadleaf herbicides of mesotrione and tembotrione instead of dicamba + tritosulfuron. Kukorelli *et al*. (2012) detected no apparent damages on homozygous cycloxydim tolerant maize through the application of 150, 400 and 800 g a.i. ha^{-1} of cycloxydim. With regard to their study, the application of cycloxydim with the mentioned doses could successfully control *Echinochloa crus-galli* (L.), *Setaria* spp. Moreover, they revealed that combined treatment of bentazon + dicamba herbicide (800 g a.i. ha^{-1} + 250 g a.i. ha^{-1}) could successfully control *Amaranthus retroflexus* L, *Chenopodium album* L, *Datura Stramonium* and other broadleaf weeds (Kukorelli *et al*., 2012).

In our study, this issue and the ineffectiveness of cycloxydim on CTM were observed up to 450 g a.i. ha^{-1}, and its application above 450 g a.i. ha^{-1} caused maize yield loses (data not shown) which might have been because of heterozygosis of the examined maize. Dotray *et al.* (2003) had conducted a similar research with similar findings on cycloxydim resistant maize. Zivojinovic *et al.* (2009) and Szel *et al.* (2010) have also stated that CTM has got a very high resistance to cycloxydim herbicide.

Vancetovic *et al.* (2009) reported that the application of 75 g a.i. ha^{-1} of cycloxydim could control *Echinohloa crus-galli* L, *Sorghum halepense* L and *Setaria spp*. They revealed that in order to control underground organs of *Sorghum halepense* L, they needed to increase cycloxydim application rate up to 150 g a.i. ha^{-1} and also in order to effectively control *Cynodon dactylon* L and *Agropyrum repens* L, 300 g a.i. ha-1 and 400 g a.i. ha^{-1} were required respectively (Vancetovic *et al.,* 2009). There were also some other similar researches reporting the application of cycloxidim at 150-300 g a.i. ha^{-1} as the best option and the most efficient treatment in this system (Kokorelli *et al*., 2012; Kokorelli *et al*., 2013; Vancetovic *et al*., 2014; Vancetovic *et al*., 2009).

In this study where broadleaf weeds were dominant during the first year and grassy weeds were dominant during the second year, this system could be an effective weed control management in corn fields in which grassy weeds are dominant. Since dicamba + tritosulfuron is a broadleaf herbicide, its application with cycloxydim is highly advised in fields with a wide range of weeds. Likewise, based on Kukorelli *et al*. (2012), horizontal resistance of Cycloxydim tolerant maize (CTM) to other grass killer herbicides such as; Quizalofop, Haloxyfop, Propaquizalofop, Fluaifop, had been approved. Clearly further research will be needed on the application of other grass killer herbicides.

The results obtained from the current study showed that combined treatment of cycloxydim herbicide during 3-4 leaf stages of maize with doses above 150 g a.i. ha^{-1} along with the application of dicamba + tritosulfuron (100 + 50 g a.i. ha^{-1}) could more efficiently control weeds in comparison with the commonly applied treatments in the region especially during mid-season. These results are in consistence with the results of Landes *et al*. (1996), Malidza and Orbović (2004) and Madiza *et al.* (2007). According to recommendations cycloxydim manufacturer, its advantages include: its efficacy in controlling perennial grassy weeds, its flexibility of usage during different growth stages of weeds and maize, its application in combination with dicamba + tritosulfuron as as a broadleaf weed herbicide and also as an efficient treatment for a wide spectrum of weeds.

Based on the results of this experiment, the effect of treatments on maize yield were lower compared to weed control (Table 6). It seems that, despite the acceptable control of combined treatments of cycloxydim with dicamba + tritosulfuron in 15, 30 and 45 days after herbicides spraying for weed control, the closure of maize canopy could control weeds after this period and could minimize the differences among treatments; further investigation is required in this regard. Generally, according to the environmental issues, the risk of weeds' resistance to herbicides and the importance of sustainable weed management, particularly managing the reduced weed seed bank, it is strongly recommended to apply cycloxidimat the rate of 100-200 g a.i. ha^{-1} plus dicamba + tritosulfuron at their recommended dose.

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مدیریت شیمیایی علف‌های هرز ذرت متحمل به سیکلوکسیدیم در ایران

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چکیده: به‌منظور معرفی برنامه جدید مدیریت شیمیایی علف‌های هرز ذرت در ایران، مطالعه‌ای در طی سال‌های ۹۴-۱۳۹۳ انجام شد. در این مطالعه ۱۵ تیمار کاربرد علف‌کش‌های رایج ذرت شامل نیکوسولفورون، فورام سولفورون، ارادیکان و توفوردی-ام‌سی‌پی‌ای در مقادیر توصیه شده و تیمارهای کاربرد علف‌کش سیکلوکسیدیم همراه با علف‌کش مخلوط دایکامبا + تریتوسولفورون در مقادیر و زمان‌های مختلف کاربرد به‌همراه دو تیمار شاهد وجین تمام فصل و عدم کنترل تمام فصل علف‌های هرز مورد بررسی قرار گرفتند. نتایج نشان داد که تأثیر تیمارهایی که در آن‌ها علف‌کش سیکلوکسیدیم به مقدار ۷۵ تا ۱۵۰ گرم ماده مؤثره در هکتار به‌کار رفتند، مشابه تأثیر علف‌کش‌های نیکوسولفورون، فورام سولفورون، ارادیکان و توفوردی-ام‌سی‌پی‌ای در کنترل علف‌های هرز بودند. اگرچه با افزایش مقدار کاربرد علف‌کش سیکلوکسیدیم در تیمارهایی که شامل این علف‌کش بودند زیست توده و تراکم علف‌های هرز به‌طور معنی‌داری کاهش یافتند، اما عملکرد دانه و زیست‌توده ذرت تحت تأثیر قرار نگرفت. با توجه به نتایج آزمایش، به‌نظر می‌رسد علی‌رغم کنترل قابل‌قبول علف‌های هرز در تیمارهایی که علف‌کش سیکلوکسیدیم با دایکامبا + تریتووسولفورون به‌کار رفتند، کانوپی ذرت توانست بر علف‌های هرز غالب شود. لذا این عامل اختلاف بین تیمارها را کاهش داد. براساس نتایج آزمایش با لحاظ کارایی سیکلوسیدیم در کنترل علف‌های هرز باریک برگ چندساله، به‌نظر می‌رسد این علف‌کش گزینه قابل‌قبولی برای کنترل علف‌های هرز ذرت در مراحل مختلف رشد آن باشد. در مجموع کاربرد ۲۰۰ تا ۳۰۰ گرم ماده مؤثره سیکلوکسیدیم همراه با دایکامبا + تریتوسولفورون بهترین تیمار از منظر اقتصادی و زیست‌محیطی می‌باشد.

واژگان کلیدی: ذرت، سیکلوکسیدیم، تحمل به علف‌کش، مقاومت به علف‌کش

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