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Original article

Determination of the efficacy of some herbicides on the weeds in safflower

Aspirdeki yabancı otlar üzerine bazı herbisitlerin etkisinin belirlenmesi

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ABSTRACT

Safflower is a conspicuous energy crop might be used as a biofuel and raw material source for vegetable oil and animal feed sectors. It has a potential to reduce energy and oil dependency of Turkey reached to a high level due to its capacity. Weeds can cause yield loss because they compete with the crop for water, light, space, and nutrients in safflower. Weed control practices, therefore, should be made efficiently to gain high safflower yield. The aim of this study is to determine the efficacy of pendimethalin, s-metolachlor, and chlorsulfuron to control weeds and the response of safflower to them. The field experiments were conducted during 2017-2019 in Gölbaşı, Ankara, Turkey. Pendimethalin and s-metolachlor were applied to the soil surface before crop sowing at 675.0, 1012.5, 1350 and 2700, and 686.25, 915.0, 1372.5 and 2745.0 g active ingredient (ai) ha^{-1}, respectively. Chlorsulfuron was treated at 3.75, 4.95, 5.625, 7.5 and 15.0 g ai ha^{-1} to the weeds when they were 2-4 true leaf stage. Responses of safflower to the herbicides and the efficacy of these herbicides on the weed were visually evaluated 14 and 28 days after treatment (DAT) and before the harvest. Pendimethalin caused very slight crop injury, and the symptoms were disappeared at 28 DAT in 2017, but same symptoms were not observed in 2018. The crop injury caused by chlorsulfuron was transient when it was applied lower than at 5.625 g ai ha^{-1}; however, chlorsulfuron at 7.5 and 15 g ai ha^{-1} injured persistently safflower plants. Pendimethalin provided moderate control on wild mustard and redroot pigweed at 1350 g ai ha^{-1} while s-metolachlor at 1372.5 g ai ha^{-1} sufficiently controlled redroot pigweeds, but not wild mustard. Weed control with chlorsulfuron at higher than 4.95 g ai ha^{-1} was good compared to lower rates.

INTRODUCTION

Oilseed crops have provided the raw material for the oil industry with the oil in their seeds and feed industry with the oil cake, which is a by-product of the vegetable oil production process. In addition to these sectors, to produce biodiesel and to supply raw materials in some branches of the industry has increased the demand for vegetable oils in the world (Bünyamin 2006). The oilseed production in Turkey has been commonly provided by olive, sunflower, cotton, rape, maize, and safflower, but the production of these crops has been far away from the meet of national consumption. Safflower is a promising energy crop used as a raw material to oil, feed and biodiesel sectors, and has a potential to reduce the dependency of the oil and energy sources mainly imported from abroad. The quality of safflower oil taste is precious like olive oil and considered very healthy by the experts (Ekin 2005). Furthermore, safflower flowers have attractive colours; so, they have commonly been added to food and beverage to enhance colour and flavour, and to prepare natural dye for cloths and carpets with its pigment namely carthamin since ancient times (Ekin 2005).

Safflower has successfully adapted to the Terrestrial Anatolia, especially Ankara, Yozgat, Konya, Muş and Çorum provinces (TÜİK 2019) because the plant has a strong root system made it as drought resistance (Lovelli et al. 2007, Amini et al. 2014). Ankara is the most important city in terms of safflower seed yield and coverage area (TÜİK 2019). Safflower production has been encouraged by additional subsidy to reduce fallow fields in these provinces, especially Ankara (Kavakoğlu ve Okur 2014, Serim et al. 2015). Other important reasons to choose safflower are the agricultural machinery used for safflower cultivation from tillage to harvest is compatible consistent with the cereal crops, heavily grown in this region, and the vegetable oil refinery may refine safflower oil without any serious modification (Babaroğlu 2007).

Some early emergent and vigorously competitive weed species like wild mustard (*Sinapis arvensis* L.) have adverse effects on safflower at the early stages of its life because the seedlings of safflower generally have a slow vegetative growth (Anderson 1985, Blackshaw et al. 1990). The suppressive effects of the weeds continue during growing season of safflower, especially preventing crop seedlings to reach sunlight by shading (Armah-Agyeman et al. 2002). Yield components, such as the number of branches and capitulum, and the weight of one thousand seed number have directly declined as weed competition has risen. As a combination of its components, the yield reduction caused by weeds in safflower was reached to 73% depending on weed species and areas in Canada (Blackshaw et al. 1989), and the weeding by hand may provide nearly one-third yield increase in Ankara Province (Uslu et al. 1998, Jalali et al. 2012). This study was conducted to determine the efficacy of the herbicides on the narrow and broad leaves weeds in safflower, and the response of the plants in the field conditions.

MATERIALS AND METHODS

Field experiments were carried out in İkizce Agricultural Research Farm in Gölbaşı, Ankara, Turkey during 2017-2019. The soil in the experimental field was clay loam with 0.7% organic matter and a pH of 7.77. The climatic conditions of the experimental fields during the study were presented in Figure 1.

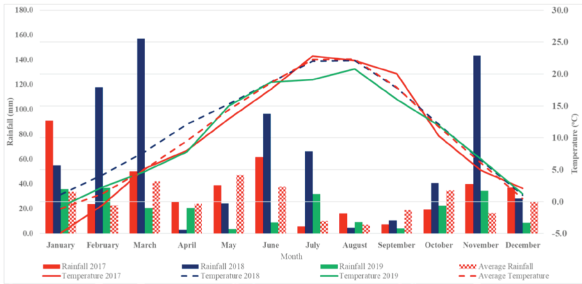

Figure 1. Meteorological data of experimental fields in 2017, 2018 and 2019

The experiment was conducted according to the Standard Herbicide Testing Procedures with minor modifications (Anonymous 2016). The herbicides were applied with a knapsack sprayer placed flat-fan nozzles (Teejet XR11002) using an application volume of 19.6 l ha^{-1} (Table 1). The pre-emergence herbicides were applied to the allocated plots, one day before safflower sowing and incorporated into the soil while the post-emergence herbicides were sprayed to the weed when they were at 2-4 true leaf stages.

The experimental design was a randomized complete block design with four replicates. The area of the plots was 20 m^2 and, the alleys between the parcels and blocks were 0.5 m and 1 m, respectively. Weedy and weed-free control parcels were also included in the experiment. The weeds in the weed-free plots were weekly removed by hand weeding. The weed species in the experimental fields and their density were presented in Table 2.

Table 1. Features of the herbicides used in the experiments

Active Ingredient	Formulation	Application Time	Rate (g ai ha^{-1})
Chlorsulfuron (%75)	DF	Post-emergence	3.75, 5.625, 7.5 and 15.0 in 2018 3.75, 4.95, 5.625 and 7.5 in 2019
Pendimethalin (450 g l^{-1})	CS	Pre-emergence	675.0, 1012.5, 1350 and 2700
S-metolachlor (915 g l^{-1})	EC	Pre-emergence	686.25, 915.0, 1372.5 and 2745.0

Table 2. Density of weed species in the experimental area (Plant m^{-2})

Weeds	2017	2018	2019
Fat hen (*Chenopodium album* L.)	0.38	0.28	0.66
Field bindweed (*Convolvulus arvensis* L.)	0.5	1.25	0.75
Wild buck weed (*Fallopia convolvulus* L.)	0.13	-	0.25
Wild mustard (*Sinapis arvensis* L.)	5.13	7.5	9.75
Redroot pigweed (*Amaranthus retroflexus* L.)	13.13	2.15	1.25
Bristly foxtail (*Setaria verticillata* (L.) P.B)	0.5	-	-
Wild oat (*Avena fatua* L.)	2.8	1.5	1.66
Common fumitory (*Fumaria officinalis* L.)	0.25	-	0,25
Groundsel (*Senecio vulgaris* L.)	0.13	-	-
False carrot (*Turgenia latifolia* (L.) Hoffm.)	0.63	-	-
Couch grass (*Elymus repens* (L.) Gould)	0.38	-	-
Shepherd-purse (*Capsella bursa-pastoris* (L.) Medik)	-	2.5	0.85
Field milk thistle (*Sonchus arvensis* L.)	-	0.88	0.75
Canada thistle (*Cirsium arvense* (L.) Scop.)	-	1.25	0.5

Crop injury and weed efficacy were visually rated using a scale of 0-100 (0 was equally no injury for safflower plants/ control for weed while 100 was completely death of crop plant/ weed) at 14 and 28 Days After Emergence (DAE) and at the harvest time (Anonymous, 2016). Efficacy of the post-emergence herbicides on the weeds and phytotoxicity depending on the herbicides were also visually evaluated using the same scale at 14 and 28 Days After Treatment (DAT) and at the harvest time. The evaluations were done by using eight-quadrats (0.5 x 0.5 m) randomly selected in the middle of the plots. The head of the safflower in the quadrats was cut manually and dried in the laboratory to determine crop yield. The safflower seeds were mechanically cleaned from the straw and adjusted to 13% moisture.

The data obtained from the experiments were subjected to analysis of variance, and the means were compared using Fisher's Least Significant Difference (LSD) test at a P value of 0.05 using SPSS statistical software (SPSS 2004). Before the statistical analyses, visual weed control and crop injury data were transformed using arcsine of the square root to normalize the variances within treatments; however, to make easily understand the original means are presented in the relevant tables (Table 3, 4 and 5).

Table 3. The effect of pendimethalin and s-metolachlor on wild mustard and redroot pigweed (%)

Herbicide	Year	Herbicide Rate	Wild mustard			Redroot pigweed		
			14 DAS	28 DAS	Harvest	14 DAS	28 DAS	Harvest
Pendimethalin	2017	675.0	57.50 d*	41.25 c	22.50 c	86.25 b	72.50 c	30.00 c
		1012.5	68.33 c	43.75 c	32.50 b	91.25 a	82.50 b	36.25 c
		1350.0	74.00 b	56.25 b	46.25 a	88.75ab	90.00 a	51.25 b
		2700.0	81.25 a	63.75 a	45.00 a	93.75 a	91.25 a	58.75 a
	2018	675.0	58.50 c	61.25 c	51.25 c	75.50 c	67.50 c	51.25 b
		1012.5	73.50 b	68.50 c	48.75 c	83.75 b	77.50 b	57.50 ab
		1350.0	81.25 a	76.50 b	63.75 b	92.50 a	78.75 b	62.75 a
		2700.0	86.50 a	81.25 a	72.50 a	96.25 a	83.75 a	66.25 a
S-metolachlor	2017	686.3	21.25 b	26.25 c	23.75 c	57.50 c	78.75 c	83.75 b
		915.0	25.00 b	35.00 b	31.67 b	71.25 b	87.50 b	86.25 b
		1372.5	32.50 a	33.75 b	37.50 b	82.50 a	96.25 a	97.50 a
		2745.0	38.75 a	41.25 a	47.50 a	87.50 a	93.75 a	95.00 a
	2018	686.3	33.50ab	31.25ab	22.50ab	50.25 c	62.50 c	63.75 d
		915.0	36.25 a	28.75 b	26.25 a	76.25 b	73.75 b	71.25 c
		1372.5	42.50 a	35.00 a	28.75 a	95.00 a	92.50 a	88.75 b
		2745.0	44.75 a	38.75 a	33.75 a	93.75 a	97.50 a	95.00 a

*Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD (P ≤ 0.05).

Table 4. The effect of various rates of chlorsulfuron on wild mustard, redroot pigweed, shepherd-purse, and field milk thistle (%)

Weed	Rate	2018			Rate	2019		
		14 DAT	28 DAT	Harvest		14 DAT	28 DAT	Harvest
Wild mustard	3.750	56.25 d*	82.50 c	85.00 b	3.750	66.25 c*	65.00 b	61.25 b
	5.625	78.50 c	91.25 b	96.50 a	4.950	83.75 b	91.25 a	92.50 a
	7.500	86.25 b	98.75 a	100.0 a	5.625	91.25 a	93.75 a	92,50 a
	15.000	91.25 a	100.0 a	100.0 a	7.500	93.75 a	91.25 a	90.00 a
Redroot pigweed	3.750	66.25 d	75.00 c	82.50 c	3.750	52.50 c	65.00 c	72.50 c
	5.625	75.00 c	91.25ab	87.50 b	4.950	63.75 b	88.75 b	85.00ab
	7.500	83.75 b	95.00 a	91.25 a	5.625	88.75 a	97.50 a	88.75 a
	15.000	96.25 a	97.50 a	90.00 a	7.500	91.25 a	98.75 a	91.25 a
Shepherd-purse	3.750	61.25 c	70.00 c	81.25 c	3.750	66.25 bc	65.00 b	63.75 b
	5.625	66.50 c	86,25 b	92.50 b	4.950	72.50 b	92.50 a	91.25ab
	7.500	86.25 b	98,75 a	100.0 a	5.625	82.50 a	95.00 a	93.75ab
	15.000	92.50 a	100.0 a	100.0 a	7.500	88.75 a	97.75 a	98.75 a
Field milk thistle	3.750	65.00 c	83.75 b	82.50 b	3.750	52.50 c	66.50 bc	72.50 c
	5.625	73.50 b	92.50 a	91.25ab	4.950	67.50 b	85.75 b	88.75 b
	7.500	90.00 a	95.00 a	96.25 a	5.625	81.25 a	93.75 a	93.75 a
	15.000	92.50 a	93.75 a	98.75 a	7.500	86.25 a	92.50 a	97.50 a

Table 5. Effects of herbicides on safflower injury (%) and safflower grain yield (kg ha $^{-1}$) and 259 yield components (cm and g) in 2017-2019

Year	Herbicide	Rate	Crop Injury (%)			Yield and Yield Components		
			14 DAS/ DAT	28 DAS/ DAT	Harvest	Plant height (cm)	1000 SW (g)	Yield (da kg^{-1}
2017	Pendimethalin	675.0	-	-	-	86.7 d*	43.4* cd	1328 c*
		1012.5	-	-	-	92.4 c	47.8 ab	1486 b
		1350.0	10	-	-	98.1 a	52.6 a	1687 a
		2700.0	10	-	-	101.3 a	51.3 a	1731 a
	S-metolachlor	686.3	-	-	-	91.2 c	46.4 bc	1145 e
		915.0	-	-	-	94.7 b	45.8 bc	1247 d
		1372.5	-	-	-	91.6 c	47.9 ab	1196 e
		2745.0	-	-	-	99.8 a	50.5 a	1278 d
	Control	-	-	-	-	76.2 e	41.3 d	978 g
2018	Pendimethalin	675.0	-	-	-	85.6 c*	41.6 cd*	1268 ef*
		1012.5	-	-	-	91.2 a	43.2 b	1326 de
		1350.0	-	-	-	90.4 a	44.8 a	1537 b
		2700.0	-	-	-	88.7 b	43.9 a	1614 a
	S-metolachlor	686.3	-	-	-	86.9 bc	40.3 d	1226 fg
		915.0	-	-	-	85.3 c	42.8 bc	1298 e
		1372.5	-	-	-	88.4 b	44.5 a	1476 c
		2745.0	-	-	-	91.1 a	43.9 b	1434 c
	Chlorsulfuron	3.750	0	0	0	83.2 d	43.2 b	1225 fg
		5.625	15	10	0	88.6 b	44.5 a	1393 d
		7.500	22.5	12.5	8.75	91.2 a	44.2 a	1568 b
		15.000	27.5	18.75	11.25	85.9 c	41.3 cd	1471 c
	Control	-	-	-	-	72.4 e	40.3 d	836 i
2019	Chlorsulfuron	3.750	-	-	-	82.4 ab*	44.12 b*	1519 d*
		4.950	10.0	-	-	84.7 a	43.65 b	1564 c
		5.625	12.5	-	-	83.5 a	46.23 a	1625 a
		7.500	17.5	12.5	-	81.9 b	48.69 a	1597 ab
	Control	-	-	-	-	62.4 c	41.92 c	628 e

*Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

RESULTS AND DISCUSSION

S-metolachlor did not provide sufficient wild mustard control at all assessments for both years while pendimethalin fairly controlled it. In previous studies, it is reported that wild mustard was not controlled by pendimethalin (Moechnig et al. 2011). Efficacy of pendimethalin on redroot pigweed decreased as increasing the time after herbicide treated into the soil. Herbicide efficacy in the first year generally was higher than the subsequent year, especially at the highest rates. Similar to pendimethalin, s-metolachlor controlled redroot pigweed at the highest rates, but weed control efficacy of s-metolachlor continued throughout the season.

Jha et al. (2017) have determined that pendimethalin and s-metolachlor at 1064 and 433 g ai ha^{-1} did not cause any injury on the safflower while they moderately and poor controlled Kochia and Russian-thistle, respectively. Weed control efficacy of pendimethalin has declined throughout the growing season, but s-metolachlor's relatively remained stable. The findings of our study are similar to Jha et al. (2017). Atanasova and Marcheva (2015) have also indicated that pendimethalin provided the highest herbicide effectiveness, but the efficacy of s-metolachlor was limited because it has a strong effect on grass weed and a limited on some broadleaves weeds. The efficacy of the herbicides on the weeds has changed depending on time and rates.

Chlorsulfuron resulted in more than 90% weed control efficacy 28 DAT except for shepherd-purse, which has a similar suppressive effect, even if it was applied at lower than recommended rate, 7.500 g ai ha^{-1}, in 2018. However, the minimum acceptable weed control level of chlorsulfuron, 5.625 g ai ha^{-1}, caused severe crop injury. So the rates used in the experiment in the second year were adjusted to the results of the first year and a lower chlorsulfuron rate, 4.950 g ai ha^{-1}, was used instead of the highest rate, 15.000 g ai ha^{-1}. A 4.950 g ai ha^{-1} chlorsulfuron rate provided good weed control for wild mustard and shepherd-purse, but the control of redroot pigweed and field milk thistle with this rate was slightly lower than others. Blackshaw et al. (1990) have similarly found that chlorsulfuron rates at higher than 4 g ai ha^{-1} provide sufficient wild mustard control. They have also indicated that control of redroot pigweed with chlorsulfuron efficiently was possible when it was applied at 11 g ai ha^{-1}. In contrast to these results, redroot pigweed in Gölbaşı, Ankara was efficiently controlled at 5.625 g ai ha^{-1} chlorsulfuron.The difference between the results of Blackshaw et al. (1990) and our study may have originated the environmental conditions and the size of weeds at the spraying time.

Anderson (1985) has determined that chlorsulfuron at 0.018-0.035 kg ai ha^{-1} had no adverse effects on safflower crop when applied post-emergence and controlled redroot pigweed, puncturevine (*Tribulus terrestris* L.) and common sunflower (*Helianthus annuus* L.), but not witchgrass (*Panicum capillare* L.). In the experimental fields, chlorsulfuron injury on the crop seedlings was higher than the findings of Anderson (1985). This difference may come out of the assessment time of herbicide application and application rates of chlorsulfuron because Anderson (1985) evaluated crop injury 3 weeks after treatment and applied higher chlorsulfuron rates. Crop injury evaluation was made three times in the experiment, and the injury was tolerated at the end of the growing season. Another reason for the crop injury caused by chlorsulfuron may be herbicide application time. Anderson (1987) has indicated that safflower seedlings might tolerate adverse effects of chlorsulfuron when applied to the crop at taller than 10 cm. Safflower was very sensitive to weed competition, especially during its early stages in Gölbaşı, Ankara; therefore, chlorsulfuron applications were done at the early stages of the seedlings. The findings of safflower injury caused by chlorsulfuron were in harmony with the results of Anderson (1987). Chlorsulfuron at 15 g ai ha^{-1} slightly reduced safflower height and 1000 seed weight similar to Anderson (1987).

In summary, the experiments in Gölbaşı, Ankara has shown that safflower was a sensitive oil crop to the weed competition and most of the weeds may be controlled pre-emergence and post-emergence herbicides. The results indicated that pendimethalin and s-metolachlor has no adverse effects on the crop even if they are applied double of recommended rates. But, their control ability on wild mustard,which is the most important weed species in safflower in Ankara province, was limited especially by s-metolachlor. Contrary to these herbicides, chlorsulfuron has provided excellent weed control in both years. However, some higher rates of chlorsulfuron caused moderately crop injury 14 and 28 DAT. The results of our study may contribute for broadleaf weed control in safflower with various herbicide options, and allow to reduce fallow areas to successfully cultivate safflower in Central Anatolian Region, especially Ankara Province. However, further studies are required to determine other herbicide options with tank mixtures or combine pre-emergence and post-emergence herbicides to control broadleaves and grass weeds.

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ÖZET

Aspir, biyoyakıt ve bitkisel yağ ile hayvan yemi sektörleri için hammadde kaynağı olarak kullanılabilecek dikkat çekici bir enerji bitkisidir. Bitki, bu kapasitesi sayesinde Türkiye'nin yüksek seviyelere ulaşan enerji ve petrole bağımlılığını azaltma potansiyeline sahiptir. Aspirdeki yabancı otlar ürünle su, ışık, alan ve besinler için rekabet ettikleri için verim kaybına neden olabilirler. Bu nedenle, aspirde yüksek verim elde etmek için yabancı ot kontrolü uygulamaları etkili bir şekilde yapılmalıdır. Bu çalışmanın amacı pendimethalin, s-metolachlor ve chlorsulfuronun yabancı otları kontrol etme etkisini ve aspirin bu herbisitlere olan tepkisini belirlemektir. Tarla denemeleri 2017-2019 yılları arasında Gölbaşı, Ankara, Türkiye'de yürütülmüştür. Pendimethalin tohum ekiminden önce 675.0, 1012.5, 1350 ve 2700 g aktif madde ha^{-1} dozlarında, s-metolachlor ise 686.25, 915.0, 1372.5 ve 2745.0 g aktif madde ha^{-1} dozlarında uygulanmıştır. Chlorsulfuron, 2-4 gerçek yaprak döneminde olan yabancı otlara 3.75, 4.95, 5.625, 7.5 ve 15.0 g aktif madde ha^{-1} dozlarında tatbik edilmiştir. Aspirin herbisitlere tepkileri ve bu herbisitlerin yabancı otlar üzerindeki etkisi, uygulamadan 14 ve 28 gün sonra ve hasattan önce gözleme dayalı değerlendirme yöntemine göre değerlendirilmiştir. Pendimethalin 2017 yılında hafif düzeyde fitotoksisiteye neden olmuş ve uygulamadan 28 gün sonra bu belirtiler kaybolmuş; ancak benzer fitotoksisite belirtileri 2018'de gözlenmemiştir. Chlorsulfuronun neden olduğu fitotoksisite, 5.625 g aktif madde ha^{-1}'den daha düşük dozlarda uygulandığında geçici iken herbisit 7.5 ve 15 g aktif madde ha^{-1}'de uygulandığında kalıcı olmuştur. Pendimethalin, 1350 g aktif madde ha^{-1}'de uygulandığında yabani hardal ve kırmızı köklü tilki kuyruğunda orta derecede kontrol sağlarken, s-metolachlor 1372.5 g aktif madde ha^{-1}'de kırmızı köklü tilki kuyruğunu etkili şekilde kontrol etmiş ancak yabani hardalı kontrol edememiştir. Chlorsulfuron ile yabancı ot kontrolü herbisitin 4.95 g aktif madde ha^{-1}'den yüksek dozlarında düşük dozlara kıyasla daha iyi bulunmuştur.

Anahtar kelimeler: Aspir, yabancı ot, herbisit, biyolojik etkinlik

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