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Yield and yield components of imidazolinone-resistant sunflower (*Helianthus annuus* L.) are influenced by pre-emergence herbicide and time of post-emergence weed removal

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ABSTRACT

With an increase in the use of imidazolinone (IMI)-resistant sunflower, it is important to determine the influence of weed interference and herbicide presence on seed yield and yield components of sunflower. The objective of this study was to determine the effect of different periods of weed presence on seed yield and yield components of IMI-resistant sunflower grown with and without pre-emergence (PRE) herbicide. Field studies were conducted in 2008 and 2009 at three locations in Serbia and one location in Nebraska, USA. A four-parameter log-logistic model described relationship between the crop yield and yield components to increasing duration of weed presence. Sunflower yield and yield components varied between years and among locations. Increasing periods of weed interference decreased yield and yield components of sunflower; however, the reductions were greater without PRE herbicide compared to the PRE herbicide treated plots. The length of time weeds could remain in the crop grown without PRE herbicide ranged from 14 to 26 days after emergence (DAE), which corresponded to the V3 (three leaves) to V4 growth stages on the basis of the 5% acceptable yield loss level. The duration of time that weeds could remain in the crop grown with PRE herbicide ranged from 25 to 37 DAE, which corresponded to the V6–V8 growth stages of sunflower. Practical implication of this study is that post-emergence weed control in IMI-resistant sunflower grown with PRE herbicide can be delayed approximately by two weeks compared to the crop grown without PRE herbicide.

1. Introduction

Sunflower (*Helianthus annuus* L.) is one of the four most important annual crops in the world grown primarily for edible oil (De la Vega and Hall, 2002). It is successfully grown over a wide geographical area as it is adaptable to a wide range of environmental conditions (Beard and Geng, 1982). Weeds, especially the broadleaf species, can cause substantial yield losses to sunflower (Bruniard and Miller, 2001; Breccia et al., 2011). For example, season-long competition by kochia (*Kochia scoparia*) densities of 0.3, 1, 3 and 6 plants m^{-1} of row decreased sunflower yield by 7, 10, 20 and 27%, respectively (Durgan et al., 1990). They also suggested that only two weeks of kochia competition after sunflower emergence decreased yield by 6%.

Control of broadleaf weeds in broadleaf crops such as sunflower often can be difficult. Sunflowers are planted in 76-cm row spacing and usually with lower planting density than many other row crops, which makes it more vulnerable to weed competition during first several weeks of growth (Bruniard and Miller, 2001). Producers have fewer herbicide options for broadleaf weed control in sunflower compared to most other row crops. They traditionally relied on pre-emergence (PRE) herbicide, which require timely rainfall, or irrigation for activation (Kerr et al., 2004). Therefore, crops that allow post-emergence (POST) applications (e.g., herbicide-resistant crops-HRCs) are attractive options for producers to effectively control broadleaf weeds in sunflower (Howatt and Enders, 2006).

Development of HRCs provided additional options for POST weed management. HRCs are dominating agricultural production systems of soybean (*Glycine max* L.) and maize (*Zea mays* L.) in the

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Table 1
Sunflower planting date, variety, pre-emergence herbicide application date, row spacing, seeding rate and harvest date at Radmilovac, Surduk and Zemun Polje in Serbia in 2008 and 2009, and at Concord, NE, USA in 2009.

Location	Year	Planting date	Variety	Herbicide application date	Row spacing (cm)	Seeding rate (seeds ha^{-1})	Harvest date
Radmilovac	2008	April 12	RIMI	April 17	70	55,000	August 26
	2009	April 15	RIMI	April 24	70	55,000	September 12
Surduk	2008	April 09	RIMI	April 17	70	55,000	August 28
	2009	April 20	RIMI	April 29	70	55,000	September 06
Zemun Polje	2008	April 09	RIMI	April 17	70	55,000	August 26
	2009	April 21	RIMI	April 28	70	55,000	September 09
Concord	2008	June 13	Croplan 528 CL	June 16	76	60,000	–[a]
	2009	May 12	Croplan 528 CL	May 14	76	60,000	September 08

[a] The study at Concord, NE, USA in 2008 was lost to early season flooding.

US, as they have provided flexible weed management practices and promote the use of reduced and no-till practices for soil conservation (Massinga et al., 2003, 2005). Even though the use of HRCs may have advantages over conventional herbicide programs, there are risks associated with their use which include potentially greater damage to non-target areas from herbicide drift or misapplication, weed resistance, weed population shifts and HRC volunteer plants in subsequent crops (Sikkema et al., 1999; Knezevic et al., 2003, 2009). Herbicide-resistant sunflower was developed by introducing an imidazolinone (IMI)-resistant gene to cultivated sunflower from wild sunflower through conventional breeding (Al-Khatib et al., 1998; Al-Khatib and Miller, 2000; Miller and Al-Khatib, 2002). IMI-resistant gene occurred as part of a mutation in wild sunflower population due to repeated use of IMI type herbicides in Kansas, USA. However, IMI herbicides (e.g., imazethapyr, imazamox) provide control of several troublesome broadleaf weeds in sunflower, which allows producers more flexibility to grow sunflower in the areas where certain broadleaf or parasitic weeds are problematic (Miller and Al-Khatib, 2002; Tan et al., 2005). In 2003, IMI-resistant sunflower was commercially registered in the US under the trade name of Clearfield® sunflower (Tan et al., 2005). In Clearfield® sunflower production systems, imazamox is currently the only IMI herbicide registered for POST use in the US, while imazamox and imazapyr are used in Europe (Tan et al., 2005).

Determination of weed interference and duration of competition on seed yield and yield components of sunflower as influenced by PRE herbicide application would help optimize the timing of POST weed control operations. Therefore, the objective of this study was to determine the effect of different periods of weed presence on seed yield and yield components of IMI-resistant sunflower grown with and without PRE herbicide.

2. Materials and methods

2.1. Study site and experimental set up

Field trials were conducted in 2008 and 2009 at one location in the US (Concord, NE; 42.37°N, 96.68°W) and three locations in Serbia, including Radmilovac (located 8 km southeast of Belgrade, the capital of Serbia; 44.75°N, 20.57°E), Surduk (situated along Danube River, 50 km northeast from Belgrade; 45.06°N, 20.30°E) and Zemun Polje (located 20 km north of Belgrade; 44.52°N, 20.20°E). The soil type at Concord, NE was a sandy loam with 64% sand, 20% silt, 16% clay, 1.6% organic matter and pH 6.3. The soil types were chernozem at Radmilovac with 45% sand, 29% silt, 26% clay, 1.5% organic matter and a pH of 7.7; calcareous chernozem at Surduk with 44% sand, 28% silt, 28% clay, 3.8% organic matter and a pH of 8.5; and calcareous chernozem at Zemun Polje with 53% sand, 30% silt, 17% clay, 3.3% organic matter and a pH of 7.8. Sunflower was planted in 76-cm row spacing in 10 m by 4.6 m plots between May 12 and June 13 depending on the year at Concord, NE (Table 1). The planting dates were between April 9 and April 21 depending on the year and location in Serbia with the row spacing of 70 cm and the plot size of 10 m by 4.2 m. Seeding rate was 60,000 seed ha^{-1} at Concord, NE and 55,000 seed ha^{-1} at all locations in Serbia (Table 1). There were six crop rows in each experimental unit. There was no irrigation applied and rainfall ranged from 163 to 213 mm in 2008 compared to 196 to 316 mm in 2009 at all locations in Serbia, whereas 381 mm rainfall was measured at Concord, NE in 2009 (Table 2).

All treatments were arranged in a split-plot design with three replications. The two main plots included herbicide presence: (1) without PRE herbicide and (2) with PRE herbicide. Sub-plots consisted of seven weed removal timings where weeds were allowed to grow until predetermined growth stage of sunflower, including: (a) four leaves (V4), (b) six leaves (V6), (c) nine leaves (V9), (d) floral head initiation (R1), (e) beginning of flowering (R5), (f) season-long weed-free and (g) season-long weedy treatments. Average sunflower development stage was determined by examining 10 consecutive plants within a single row selected in each plot. Sunflower development stage was on the basis of the number of fully developed leaves per plant (vegetative growth) or various

Table 2
Total monthly precipitation and average temperature for the growing season of April through August at Radmilovac, Surduk and Zemun Polje in Serbia in 2008 and 2009, and for the months of May through August at Concord, NE, USA in 2009.

Location	Month	Precipitation (mm)		Temperature (°C)			
		2008	2009	2008		2009	
				Min	Max	Min	Max
Radmilovac	April	22	5	8.6	16.6	10.5	21.2
	May	46	34	13.4	23.3	14.3	25.3
	June	85	153	17.6	27.1	16.3	26.0
	July	34	79	18.1	27.7	18.5	29.5
	August	26	45	17.5	30.3	19.0	30.0
Surduk	April	26	2	10.6	19.7	8.4	20.8
	May	40	50	13.6	25.0	12.1	24.7
	June	37	124	17.7	28.2	14.3	24.8
	July	46	87	18.5	28.5	15.9	29.5
	August	14	40	19.0	30.7	16.6	30.4
Zemun Polje	April	27	6	11.8	19.7	10.0	20.7
	May	40	28	14.2	26.5	14.2	25.6
	June	36	72	18.7	29.2	16.1	26.1
	July	46	31	19.5	28.8	18.4	29.5
	August	14	59	20.0	30.7	18.8	29.9
Concord	May	–[a]	45	–	–	8.9	27.8
	June	–	109	–	–	13.3	25.6
	July	–	104	–	–	13.9	26.7
	August	–	123	–	–	14.0	27.8

[a] The study at Concord, NE, USA in 2008 was lost to early season flooding.