Weed Science, 48:461–466. 2000

ALS-resistant *Helianthus annuus* interference in *Glycine max*

Jayla R. Allen
Department of Agronomy, University of Missouri, Columbia, MO 65211

William G. Johnson
Corresponding author. Department of Agronomy, University of Missouri, Columbia, MO 65211; johnsonwg@missouri.edu

Reid J. Smeda
Department of Agronomy, University of Missouri, Columbia, MO 65211

Robert J. Kremer
USDA-ARS Cropping Systems and Water Quality Research Unit, University of Missouri, Columbia, MO 65211

Field studies were conducted to determine the effect of early-season and early- plus late-season acetolactate synthase–resistant *Helianthus annuus* interference on *Glycine max* and *H. annuus* growth and yield at two sites in Missouri. *Helianthus annuus* densities of 3 plants m^{-2} were established shortly after *G. max* emergence in all plots except the weed-free check. To study early-season interference, *H. annuus* were removed with postemergence glyphosate (0.84 kg ae ha^{-1}) 2, 4, 6, and 8 wk after planting (WAP) and kept weed-free for the rest of the growing season. *Glycine max* yields were not different with 2, 4, 6, or 8 wk of early-season interference at either location. To study early- plus late-season interference, *H. annuus* densities were established at 3 plants m^{-2}. They were then removed 2, 4, 6, or 8 WAP with glyphosate and subsequently reestablished at the same density within 2 wk after removal by newly emerging and transplanted *H. annuus.* These *H. annuus* were allowed to remain in the field for the remainder of the growing season. This provided a weed-free period of approximately 2 wk during the growing season beginning 2, 4, 6, or 8 WAP. Season-long interference and no-interference treatments were also included. *Glycine max* yields were reduced 47 to 72% with season-long interference. *Helianthus annuus* vegetative dry matter was approximately 56% lower at Columbia than at Miami. *Glycine max* yields tended to increase as the weed-free period was delayed into the growing season. Early-season weed-free periods (2 to 4 and 4 to 6 WAP) allowed *H. annuus* to become re-established before *G. max* formed a canopy and resulted in larger amounts of *H. annuus* biomass and seed production as well as *G. max* yield losses of 15 to 80%. Re-establishment of *H. annuus* in 6 to 8 WAP and 8 to 10 WAP weed-free treatments generally resulted in the plants surviving for only a few weeks after establishment and not producing seed or reducing *G. max* yield.

Nomenclature: Glyphosate; *Helianthus annuus* L. HELAN, common sunflower; *Glycine max* (L.) Merr 'Asgrow 3601', soybean.

Key words: Carrying capacity, weed competition, critical weed-free period.

Helianthus annuus (common sunflower) is an important broadleaf weed in *Glycine max* (soybean) fields because of high yield loss potential (Geier et al. 1996; Irons and Burnside 1982). *Helianthus annuus* biotypes differ greatly, with heights ranging from 0.2 to 5.0 m, production of multiple heads (17 or more) ranging from 2 to 4.5 cm in diameter (Stubbendieck et al. 1994), and seed production up to 7,750 seeds $plant^{-1}$ (Anderson 1996). Previous competition studies have determined that *H. annuus* is one of the most competitive weeds in *G. max* (Geier et al. 1996; Irons and Burnside 1982). A study in eastern Kansas showed season-long *H. annuus* interference at a density of 3 plants m^{-2} reduced *G. max* yield 85% (Geier et al. 1996). In a Nebraska study, *H. annuus* removal within 2 wk after planting and *G. max* kept weed-free for a period of 4 to 6 wk were needed for maximum yields (Irons and Burnside 1982). These researchers concluded the mechanisms of interference included competition for light (Geier et al. 1996) and production of allelopathic substances (Irons and Burnside 1982).

Acetolactate synthase (ALS)-resistant *H. annuus* was reported in Missouri (Johnson et al. 1997), Kansas (Baumgartner et al. 1997), and South Dakota (White et al. 1997) in 1997. Studies at the Missouri site conducted in 1998 and 1999 found a population of *H. annuus* that was not controlled with flumetsulam, imazethapyr, chlorimuron, imazaquin, cloransulam, CGA-277476 {2-[[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid, 3-oxetanyl ester}, or imazamox with one and two times the normal herbicide usage rates in *G. max* (Allen 1999). In Kansas, a *H. annuus* population was found to be 170 times more resistant to imazethapyr than a susceptible biotype at a rate required for 25% control of the weed (Al-Khatib et al. 1998). In addition, a *H. annuus* population in South Dakota was not controlled at 16 times the normal use rate of imazethapyr (White et al. 1997).

In 1997 and 1998, we conducted a survey to determine the geographical distribution of ALS-resistant *H. annuus* in Missouri (Allen 1999). In this study, 26 *H. annuus* biotypes were subjected to postemergence treatments of one and five times the normal use rates of imazethapyr, imazaquin, and chlorimuron. All of the biotypes screened were resistant to imazethapyr, 78% were resistant to imazaquin, and 73% were resistant to chlorimuron at the normal use rate. Resistance to all three herbicides was found in 70% of the biotypes. Field history data showed selection pressure with imazethapyr and imazaquin was relatively low, but chlorimuron was used over 75% of the time in *G. max*. Overall, the selection pressure with ALS inhibitors was extremely high, especially where ALS inhibitors were also used in *Zea mays* L. (corn). The most popular management strategy mentioned by the survey participants to manage ALS-resistant

Table 1. Dates of *Glycine max* planting, herbicide application, *Helianthus annuus* removal dates, and *G. max* and *H. annuus* harvest for Columbia and Miami, MO, for 1998 and 1999.[a]

	Columbia		Miami	
	1998	1999	1998	1999
G. max planting dates	May 11	May 8	May 9	June 6
Herbicide application PRE[b]	May 11	May 8	May 11	June 7
H. annuus removal dates				
2 WAP	May 27	May 21	May 23	June 20
4 WAP	June 12	June 4	June 4	July 6
6 WAP	June 24	June 18	June 17	July 19
8 WAP	July 7	June 30	July 2	Aug 2
G. max and *H. annuus* harvest	Sept 23	Sept 22	Oct 6	Oct 15

[a] Abbreviations: PRE, preemergence; WAP, weeks after planting.
[b] *S*-metolachlor (1.41 kg ha^{-1}) applied for annual grass and small-seeded broadleaf weed control.

H. annuus was to apply glyphosate in glyphosate-resistant *G. max* (Allen 1999).

As a result, it is anticipated that a majority of ALS-resistant *H. annuus* in Missouri will be controlled with glyphosate-based herbicide programs in glyphosate-resistant *G. max*. However, because glyphosate lacks residual activity, some *H. annuus* may emerge after glyphosate is applied. Therefore, the objective of this study is to determine the effect of early-season and early- plus late-season ALS-resistant *H. annuus* interference on *G. max* and *H. annuus* growth and yield at two geographical regions in Missouri.

Materials and Methods

Field studies were conducted in 1998 and 1999 in a grower's field near Miami in the Missouri River bottom in central Missouri, where ALS-resistant *H. annuus* was first found (Johnson et al. 1997), and in Columbia, MO, at the University of Missouri Agronomy Research Center. At Miami, the soil was a Haynie very fine sandy loam soil (coarse-silty, mixed, Calcareous, mesic Mollic Udifluvents) consisting of 1.7% organic matter (OM), 28% sand, 48% silt, and 24% clay, pH 7.5 and cec 12.5 meq $(100\ g)^{-1}$. At Columbia, the soil was a Mexico silt loam soil (fine, montmorillonitic, Mesic, Aeric Vertic Epiaqualf) located on the prairie claypan region, consisting of 2.6% OM, 7% sand, 75% silt, and 18% clay, pH 7.3 and cec 14.7 meq $(100\ g)^{-1}$.

The experimental design at each site was a randomized complete block with four replications. The experimental area was fall chisel plowed and field cultivated prior to planting at Columbia in 1998 and 1999 and Miami in 1998. In 1999, the Miami location was fall chisel plowed and disked in the spring. Fertilizer applications were made in accordance with soil test recommendations. Plots consisted of four rows 10.7 m long spaced 76 cm apart. Asgrow 3601 (glyphosate and sulfonylurea resistant) *G. max* was planted approximately 2.5 cm deep at a rate of 346,000 seeds ha^{-1} on May 9, 1998, and June 6, 1999, at Miami and on May 11, 1998, and May 8, 1999, at Columbia. Seed was collected from escaped plants at Miami in 1997 and used to overseed the experimental areas at both locations in 1998 and 1999. All herbicide applications were made with a CO_2-pressurized backpack sprayer at a carrier volume of 187 L ha^{-1} using flat fan XR8003[1] nozzles at a ground speed of 4.8 km h^{-1}. Metolachlor (1.41 kg ha^{-1}) was applied preemergence over the entire experimental area to control annual grasses and small-seeded broadleaf weeds.

In eastern Kansas, season-long interference by three *H. annuus* plants m^{-2} reduced *G. max* yield 85% (Geier et al. 1996). Based on these results, the initial *H. annuus* density was set at 3 plants m^{-2} in each plot, except the weed-free check, within 2 wk of planting. The densities were established by thinning or transplanting into plots with sparse infestations. The following sets of treatments were evaluated in a single field experiment at each site.

Early-season H. annuus *interference. Helianthus annuus* densities were established as mentioned earlier, and glyphosate (0.84 kg ae ha^{-1}) was applied 2, 4, 6, and 8 wk after planting (WAP) as the means of *H. annuus* removal. After the glyphosate treatment, these treatments were kept weed-free by hand hoeing for the rest of the season to evaluate the relationship between early-season weed interference and *G. max* yield.

Early- plus late-season H. annuus *interference. Helianthus annuus* densities were established as mentioned above and glyphosate was applied 2, 4, 6, and 8 WAP as means of *H. annuus* removal as in the early-season interference treatments. In addition, *H. annuus* densities were re-established at 3 plants m^{-2} in these treatments by transplanting and subsequent emergence within 2 wk of herbicide application to evaluate the relationship between early- plus late-season interference and *G. max* yield. This provided a weed-free period of approximately 2 wk during the growing season beginning 2, 4, 6, or 8 WAP of *G. max*. *Helianthus annuus* densities were maintained throughout the growing season by handweeding and transplanting. A treatment in which a *H. annuus* density of 3 m^{-2} was maintained for the entire season and a treatment that was maintained weed-free for the entire season was also included. A complete listing of spray dates and weather data are shown in Tables 1 and 2, respectively.

Just prior to *G. max* harvest, *H. annuus* biomass and seed production was determined by harvesting five random plants within each plot. Plants were cut at the soil surface and the heads were separated from the plant and placed in separate cloth bags. All plant tissue was dried in an air dryer[2] for 48 h at 37 C. The total dry vegetative matter per harvested area, excluding heads and seeds, was converted to grams per plant. The seeds were weighed after drying and threshing

Table 2. Average air temperature and total precipitation of May through October at Columbia and Miami, MO, in 1998 and 1999.

	Temperature				Precipitation[a]			
	Columbia		Miami		Columbia		Miami	
Month	1998	1999	1998	1999	1998	1999	1998	1999
	C				cm			
May	21	18	20	18	5	9	6	13
June	23	23	22	24	14	13	27	15
July	25	27	24	27	13	0	11	5
August	28	25	25	25	3	5	19	6
September	23	19	22	20	14	5	20	17
October	15	14	15	14	14	4	19	3
Mean	23	21	21	21	—	—	—	—
Total	—	—	—	—	63	36	102	59

[a] The Columbia location was irrigated on May 18, 1998 (3 cm), June 17, 1999 (4 cm), and August 30, 1999 (4 cm).

Table 3. *Glycine max* yields at Columbia and Miami, MO, in 1998 and 1999 with early-season *Helianthus annuus* interference.[a]

	G. max yield			
	Columbia		Miami	
H. annuus removal dates	1998	1999	1998	1999
	kg ha^{-1}			
Weed-free check	2,113	2,415	2,772	3,244
None[b]	1,430	1,216	1,480	905
2 WAP	2,162	2,551	2,708	3,295
4 WAP	2,190	2,514	2,837	3,071
6 WAP	2,120	2,374	2,792	3,163
8 WAP	2,023	2,265	2,929	2,949
LSD (0.05)	ns	ns	ns	ns

[a] Abbreviations: WAP, weeks after planting; ns, not significant.
[b] *Helianthus annuus* interference (3 plants m^{-2}) for the entire growing season.

from the heads. The number of seeds per harvested area was converted to seeds per plant.

Glycine max stand counts and plant heights were collected from two, 1-m-long areas in each plot row at harvest. *Glycine max* yield at Columbia in 1998 and 1999 and at Miami in 1999 was determined by harvesting the center two rows of each plot with a plot combine. *Glycine max* yield at Miami in 1998 was determined by hand harvesting 1 m of row from each of the two center rows in each plot because river flooding was anticipated. All seed weights were adjusted to 13% moisture.

Glycine max yield, height, and density were subjected to ANOVA and tested for homogeneity. Significant interactions between years and locations were observed for *H. annuus* height, biomass production, and seed production, and these data were analyzed separately for each location and year. Means were separated with Fisher's Protected LSD at P = 0.05. Regression techniques were used to determine the relationship between *G. max* yield and *H. annuus* biomass production by standard regression diagnostics after performing various transformations of the independent and dependent variables. The best fitting line was a regression of *G. max* yield on the square root of *H. annuus* biomass (dry weight) per plant.

Results and Discussion

Season-long H. annuus *interference*. On the well-drained alluvial soil at Miami, *G. max* yields were reduced 47 and 72% of the weed-free check in 1998 and 1999, respectively, when *H. annuus* was allowed to interfere all season (Table 3). At Columbia on the poorly drained claypan soil, *G. max* yields were reduced by 32 and 50% in 1998 and 1999, respectively, of the weed-free check when *H. annuus* was allowed to interfere all season.

Early-season H. annuus *interference. Helianthus annuus* interference had no effect on *G. max* height or *G. max* density at harvest in any treatment (data not shown). *Glycine max* yields were not reduced by 2, 4, 6, or 8 wk of *H. annuus* interference at either location (Table 3). Although this experiment showed that *G. max* can withstand *H. annuus* interference of 3 plants m^{-2} up to 8 WAP without a yield loss, three of the four site years showed a trend of declining yields with 8 wk of interference.

Early- plus late-season H. annuus *interference. Helianthus annuus* interference had no effect on *G. max* height or *G. max* density at harvest in any treatment (data not shown). In 1998, *H. annuus* were re-established in the 6 to 8 and 8 to 10 WAP weed-free treatments but died after a few weeks and did not produce seed or reduce *G. max* yield. In 1999, *H. annuus* re-established in the 6 to 8 and 8 to 10 WAP weed-free treatments at Columbia survived; however, only a few sunflowers survived in the 6 to 8 WAP weed-free treatment, and none survived in the 8 to 10 WAP weed-free treatment at Miami in 1999. Subsequently, *H. annuus* that was re-established late in the growing season was less likely to survive until *G. max* harvest because of dry soil conditions and the shading effect of the *G. max* canopy.

Helianthus annuus biomass production was two to three times higher at Miami on the well-drained alluvial soil than on the poorly-drained claypan soil at Columbia, especially with season-long *H. annuus* interference and the 2 to 4 WAP weed-free treatment (Table 4). This was an indication that *H. annuus* was not as vigorous on the claypan soil as it was on the alluvial soil. Dry matter production decreased significantly as the weed-free period was delayed into the growing season at both locations. The early weed-free pe-

Table 4. *Helianthus annuus* aboveground biomass production (dry weight) at Columbia and Miami, MO, in 1998 and 1999 in treatments with early- plus late-season *H. annuus* interference.[a]

	H. annuus biomass			
	Columbia		Miami	
Weed-free period	1998	1999	1998	1999
	g plant^{-1}			
None[b]	289	376	880	580
2–4 WAP	161	252	631	567
4–6 WAP	53	228	241	235
6–8 WAP	—	71	—	37
8–10 WAP	—	9	—	—
LSD (0.05)	119	133	130	184

[a] WAP, weeks after planting. A dash (—) indicates that no *H. annuus* plants were present at *G. max* harvest.
[b] *Helianthus annuus* interference (3 plants m^{-2}) for the entire growing season.

Table 5. *Helianthus annuus* height at Columbia and Miami, MO, in 1998 and 1999 in treatments with early- plus late-season *H. annuus* interference.[a]

	H. annuus height			
	Columbia		Miami	
Weed-free period	1998	1999	1998	1999
	cm			
None[b]	258	271	347	330
2–4 WAP	214	257	292	283
4–6 WAP	177	213	210	191
6–8 WAP	—	162	—	94
8–10 WAP	—	94	—	—
LSD (0.05)	34	23	30	43

[a] WAP, weeks after planting. A dash (—) indicates that no *H. annuus* plants were present at *G. max* harvest.
[b] *Helianthus annuus* interference (3 plants m^{-2}) for the entire growing season.

Table 6. *Helianthus annuus* seed production at Columbia and Miami, MO, in 1998 and 1999 in treatments with early- plus late-season *H. annuus* interference.[a]

	H. annuus seed production			
	Columbia		Miami	
Weed-free period	1998	1999	1998	1999
	seeds $plant^{-1}$			
None[b]	16,583	4,165	28,933	1,210
2–4 WAP	9,060	4,072	24,893	1,250
4–6 WAP	4,687	2,455	12,795	1,270
6–8 WAP	—	854	—	197
8–10 WAP	—	44	—	—
LSD (0.05)	5,217	1,119	7,942	1,069

[a] WAP, weeks after planting. A dash (—) indicates that no *H. annuus* plants were present at *G. max* harvest.
[b] *Helianthus annuus* interference (3 plants m^{-2}) for the entire growing season.

riods allowed *H. annuus* to re-establish and cause more late-season interference and produce more *H. annuus* biomass.

Helianthus annuus dry weight biomass production was 289, 376, 880, and 580 g $plant^{-1}$ at Columbia and Miami in 1998 and 1999, respectively, when allowed to compete the entire season (Table 4). A study conducted in Kansas found that at the same densities, dry weight biomass production was 400 and 266 g $plant^{-1}$ in 1991 and 1992, respectively (Geier et al. 1996). *Helianthus annuus* biomass accumulation at Miami was greater than in Kansas, probably because of the rainfall and high overall productivity of the soil at Miami and because the *H. annuus* in the Kansas study trials were established in a 25-cm band over the *G. max* row. This probably resulted in more interference from *G. max* on *H. annuus* growth. *Helianthus annuus* biomass production at Columbia was comparable to *H. annuus* biomass production reported in the Kansas study.

Helianthus annuus was slightly taller at Miami than at Columbia (Table 5). This is another indication of the more vigorous growth habit on the alluvial soil than on the claypan soil. *Helianthus annuus* height was also significantly reduced as the weed-free period was delayed.

Helianthus annuus seed production per plant was higher in 1998 than in 1999 at both locations (Table 6). *Helianthus annuus* seed production was greater at Miami than at Columbia in 1998 because of the increased vigor observed with *H. annuus* grown on the alluvial soil at Miami. *Helianthus annuus* seed production at Miami was greater in 1998 than 1999 because of the late planting of the 1999 study and the subsequent late harvest, which resulted in approximately 80% shattering loss at the time of *G. max* harvest in 1999. *Helianthus annuus* seed production at Columbia was significantly higher in 1998 than 1999 because of the drought conditions during seed set in 1999. However, *H. annuus* survival and subsequent seed production occurred in all re-established treatments at Columbia in 1999 because of favorable environmental conditions at re-establishment timing and poor *G. max* canopy development later in the season. *Helianthus annuus* seed weight was higher at Miami (132 and 100 seeds g^{-1}) than in Columbia (157 and 152 seeds g^{-1}) in 1998 and 1999, respectively. This is probably a result of the increased vigor at Miami making it possible to store additional nutrients in the seed.

Our results show that on the well-drained alluvial soil at Miami, *G. max* yields were reduced by 47 and 72% of the weed-free check in 1998 and 1999, respectively, when *H. annuus* was allowed to interfere the entire season (Table 7). At Columbia on the poorly-drained claypan soil, *G. max* yields were reduced by 32 and 50% of the weed-free check in 1998 and 1999, respectively, when *H. annuus* was allowed to interfere the entire season. Our yield reductions were not quite as severe as those observed in Kansas, where *H. annuus* at the same density reduced *G. max* yield by 85% with season-long competition (Geier et al. 1996). This is probably because the *H. annuus* densities were established in a 25-cm band over the *G. max* row in the Kansas study, whereas the *H. annuus* densities were established randomly throughout an area 1.5 m wide over two *G. max* rows in our research. Establishing the *H. annuus*, on average, closer to the *G. max* row likely increased the competitive effects of the weed and *G. max* on each other.

Our study shows the longer the late-season interference period, the greater the *H. annuus* biomass production and the greater the *G. max* yield loss (Tables 4, 5, and 7; Figure 1). A more severe *G. max* loss resulted at Miami in 1999 vs. 1998 as *H. annuus* biomass increased. Although biomass production was somewhat similar between years at this lo-

Table 7. *Glycine max* yields at Columbia and Miami, MO, in 1998 and 1999 with early- plus late-season *Helianthus annuus* interference.[a]

	G. max yield			
	Columbia		Miami	
Weed-free period	1998	1999	1998	1999
	kg ha^{-1}			
Season-long	2,113	2,415	2,772	3,244
None[b]	1,430	1,216	1,480	905
2–4 WAP	1,807	1,286	2,003	651
4–6 WAP	1,991	1,939	2,520	3,081
6–8 WAP	2,018	2,008	3,114	3,112
8–10 WAP	2,099	2,433	2,965	2,796
LSD (0.05)	218	448	695	381

[a] WAP, weeks after planting.
[b] *Helianthus annuus* interference (3 plants m^{-2}) for the entire growing season.

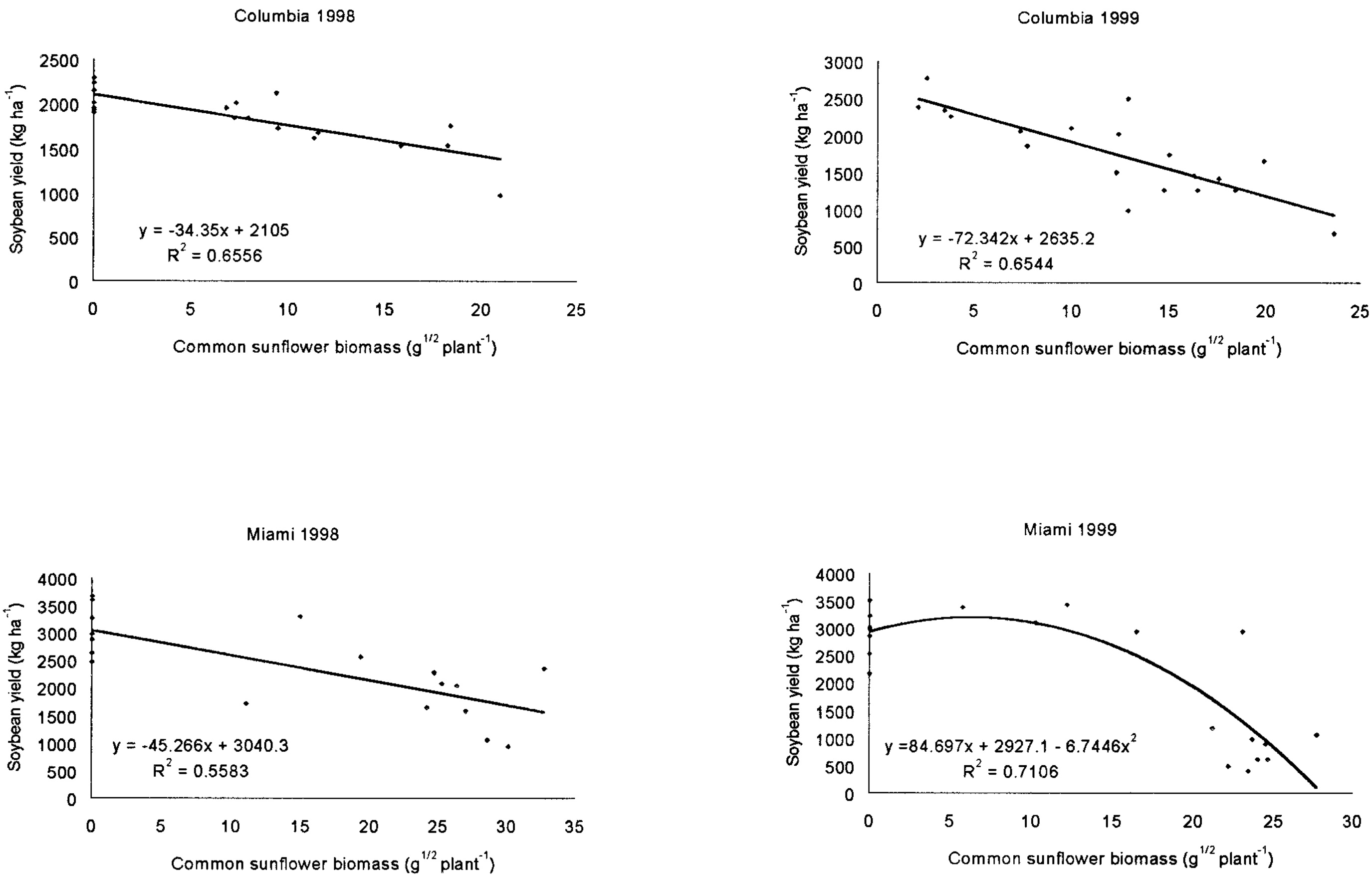

FIGURE 1. Relationship between end-of-season *Helianthus annuus* biomass and *Glycine max* yield at Columbia and Miami, MO, in 1998 and 1999 in treatments with early- plus late-season *H. annuus* interference.

cation, dry weather conditions at *G. max* seed set likely increased the competitive effects of *H. annuus* on *G. max*. *Glycine max* yield was less affected by the later re-establishment periods, which also resulted in less *H. annuus* biomass production. Regression analysis indicated that the relationship between *G. max* yield and *H. annuus* biomass production was best described by regressing *G. max* yield on the square root of *H. annuus* biomass. Statistically significant yield reductions occurred when *H. annuus* biomass production per plant was 55 and 30 g plant^{-1} at Columbia and 52 and 27 g plant^{-1} at Miami in 1998 and 1999, respectively. Significant *G. max* yield reductions occurred with lower *H. annuus* biomass weights in 1999 than 1998 at both locations, which is likely due to higher temperatures and lower rainfall in July 1999. Temperatures at both locations were 2 to 3 C higher in 1999 than 1998, and rainfall was 0 and 5 cm in 1999 and 13 and 11 cm in 1998 at Columbia and Miami, respectively, consequently limiting the carrying capacity of both soils in 1999 (Aldrich and Kremer 1997). Although differences in the relationship between *G. max* yield reduction and *H. annuus* biomass production were observed between years, there were only minor differences between locations. This indicates that the competitive ability of the *G. max* variety utilized was relatively consistent across locations and was reduced by high temperatures and low precipitation in July of 1999 regardless of soil type.

The earlier *H. annuus* is removed from *G. max*, the more likely re-established plants will survive until *G. max* harvest. Furthermore, early *H. annuus* removal and, subsequently, early re-establishment results in increased probability for a significant *G. max* yield reduction because of *H. annuus* interference. Thus, the later the glyphosate application is made in the growing season to control *H. annuus*, the less likely re-establishment will occur. Glyphosate provided adequate control of *H. annuus* up to 76 cm in height in this study (data not shown). The lack of significant *G. max* yield reduction by up to 8 wk of *H. annuus* interference also promotes a later application of glyphosate for the control of ALS-resistant *H. annuus* in *G. max*.

A later application of glyphosate creates difficulty for control of other hard-to-control weeds like *Ipomoea* sp. (morningglory), *Abutilon theophrasti* (L.) Medicus (velvetleaf), or *Polygonum pensylvanicum* L. (Pennsylvania smartweed). By delaying glyphosate applications to prevent re-establishment of *H. annuus*, control of other weeds may be sacrificed. In this situation, a sequential application of glyphosate can be used to attain adequate control of all weeds present. The only other alternative herbicide for the control of ALS-resistant *H. annuus* in Missouri is bentazon, which must be applied in sequential applications 10 d apart at 0.56 kg ha^{-1} to attain adequate control in *G. max* (Allen 1999).

Helianthus annuus is one of the most competitive annual broadleaf weeds in midwestern *G. max* production (Geier et al. 1996; Holm et al. 1991; Irons and Burnside 1982; Stoller et al. 1987). Our research suggests that the critical period of *H. annuus* control is 4 to 8 WAP. Controlling *H. annuus* 4 to 8 WAP resulted in yields statistically equivalent to the weed-free check and minimal amounts of re-establishment.

A Nebraska study found that *H. annuus* needed to be removed 2 WAP and *G. max* kept weed-free for 4 to 6 WAP to prevent *G. max* yield loss (Irons and Burnside 1982). The differences in the critical period for *H. annuus* control is probably due to the differences in *H. annuus* populations in our study (3 plants m^{-2}) vs. the Nebraska study (220 plants m^{-2}), which resulted in an earlier critical weed-free period in the Nebraska study. Thus, critical weed-free periods are dependent on weed densities, especially with large-seeded broadleaf weeds such as *H. annuus*

Sources of Materials

[1] TeeJet XR8003. Spraying Systems Co., North Avenue, Wheaton, IL 60188.

[2] Dwyer. F. W. Dwyer Mfg. Co., Michigan City, IN 46360.

Acknowledgments

Excellent technical assistance was provided by Jim Wait, Cheryl Holman, Jeremy Dirks, Pauley Bradley, and Kaleb Hellwig. Contribution from the University of Missouri Agricultural Experiment Station, Journal Series 13,015. Mention of trademark, proprietary product, or vendor does not constitute endorsement of the product by the U.S. Department of Agriculture or the University of Missouri and does not imply approval to the exclusion of other products that may be suitable.

Literature Cited

Aldrich, R. J. and R. J. Kremer. 1997. Principles in Weed Management. 2nd ed. Ames, IA: Iowa State University Press. 55 p.

Al-Khatib, K., J. R. Baumgartner, D. E. Peterson, and R. S. Currie. 1998. Imazethapyr resistance in common sunflower (*Helianthus annuus*). Weed Sci. 46:403–407.

Allen, J. R. 1999. Management, Distribution, and Interference of ALS-Resistant Common Sunflower in Missouri Soybean. M.S. thesis. University of Missouri–Columbia. 139 p.

Anderson, W. P. 1996. Weed Science: Principles and Applications. 3rd ed. Minneapolis/St. Paul, MN: West Publishing. 28 p.

Baumgartner, J. R., K. Al-Khatib, R. S. Currie. 1997. Imazethapyr resistance in common sunflower. Proc. North Cent. Weed Sci. Soc. 52: 162.

Geier, P. W., L. D. Maddux, L. J. Moshier, and P. W. Stahlman. 1996. Common sunflower (*Helianthus annuus*) interference in soybean (*Glycine max*). Weed Technol. 10:317–321.

Holm, L. G., D. L. Plucknett, J. V. Pancho, and J. P. Herberger. 1991. The World's Worst Weeds: Distribution and Biology. Malabar, FL: Krieger Publishing Company. pp. 479–481.

Irons, S. M. and O. C. Burnside. 1982. Competitive and allelopathic effects of sunflower (*Helianthus annuus*). Weed Sci. 30:372–377.

Johnson, W. G., R. J. Smeda, J. R. Miller, C. S. Holman, and J. D. Wait. 1997. ALS-resistant common sunflower in Missouri. Proc. North Cent. Weed Sci. Soc. 52:132–133.

Stoller, E. W., S. K. Harrison, L. M. Wax, E. E. Regnier, and E. D. Nafziger. 1987. Weed interference in soybean (*Glycine max*). Rev. Weed Sci. 3:155–181.

Stubbendieck, J., G. Y. Friisoe, and M. R. Bolick. 1994. Weeds of Nebraska and the Great Plains. Lincoln, NE: Nebraska Department of Agriculture, pp. 144–145.

White, A. D., D. K. Owen, R. G. Hartzler, and J. Cardina. 1997. Evaluation of common sunflower (*Helianthus annuus*) resistance to acetolactate synthase inhibiting herbicides. Weed Sci. Soc. Am. Abstr. 38: 11.20.

Received January 14, 2000, and approved April 2, 2000.