Weed Technology 2012 26:137–144

Education/Extension

Economic Evaluation of Common Sunflower (*Helianthus annuus*) Competition in Field Corn

Nyland R. Falkenberg, Todd J. Cogdill, M. Edward Rister, and James M. Chandler*

Field studies were conducted near College Station, TX, in 2006 and 2007 to evaluate the economic impact of common sunflower interference in field corn. A density of one common sunflower per 6 m of crop row caused a yield loss of 293 kg ha^{-1}. Estimated losses at a net corn price of \$0.08 kg^{-1} was \$92 ha^{-1} for infestation levels of four common sunflower plants per 6 m of row. Corn yield was increased by 32 kg ha^{-1} by each 1,000 plant ha^{-1} increase in corn planting density. Corn planting densities of 49,400 and 59,300 plants ha^{-1} provided the greatest net returns with or without the presence of common sunflower competition. Corn yields were reduced by extended duration of sunflower competition, with losses exceeding 1,500 kg ha^{-1} per week and increasing in magnitude at a decreasing rate throughout the growing season. Herbicide treatments provided net returns of \$600 to \$1,300 ha^{-1} above no weed control in both 2006 and 2007. Net returns of \$609 and \$653 ha^{-1} were obtained without the use of any herbicide for sunflower control. Determining the economic impact of common sunflower interference in field corn allows producers to estimate the overall net return on the basis of duration of common sunflower interference and density, while considering varying net corn prices, crop planting density, and herbicide application costs.

Nomenclature: Common sunflower, *Helianthus annuus* HELAN; corn, *Zea mays* L. 'DLP 69-71'.

Key words: Density, duration, herbicidal control, marginal economic analyses, net corn prices, net returns.

En 2006 y 2007 se realizaron estudios de campo cerca de College Station, TX, para evaluar el impacto económico de la interferencia de *Helianthus annuus* en el cultivo del maíz. Una densidad de una planta de *H. annuus* por *cada* 6 m de surco causó una pérdida de rendimiento de 293 kg ha^{-1}. Las pérdidas estimadas, con un precio neto de maíz de \$0.08 por kg^{-1}, fue de \$92 ha^{-1} para los niveles de infestación de 4 plantas de *H. annuus* por cada 6 m de surco. El rendimiento del maíz aumentó en 32 kg ha^{-1} por cada incremento de 1,000 plantas ha^{-1} en la densidad de siembra. Las densidades de siembra del maíz de 49,400 y 59,300 plantas ha^{-1} proporcionaron las mayores utilidades netas con o sin la presencia de competencia de *H. annuus.* Los rendimientos del maíz se redujeron en el caso de una extendida duración de la competencia de *H. annuus,* con pérdidas superiores a 1,500 kg ha^{-1} por semana y con un incremento en su magnitud a una taza decreciente a lo largo del ciclo del cultivo. Los tratamientos de herbicida proporcionaron utilidades netas de \$ 600 a \$1,300 ha^{-1} por arriba de situaciones sin control de malezas en ambos años. Utilidades netas de \$609 y \$653 ha^{-1} se obtuvieron sin el uso de algún herbicida para el control de *H. annuus.* Determinar el impacto económico de la interferencia de *H. annuus* en el cultivo de maíz, permite a los productores estimar el rendimiento neto total en base a la duración de la interferencia y la densidad de *H. annuus*, tomando en cuenta la variación en los precios netos del maíz, la densidad de siembra y los costos de aplicación del herbicida.

Common sunflower is a member of the extensive Asteraceae family. This species is an annual native dicot that has been observed for more than 3,000 yr. Nearly all parts of the plant were used by Native Americans. It grows in disturbed areas, along roadsides, creek banks, dry prairies, and in fields of numerous row crop species (Geier et al. 1996; Irons and Burnside 1982). Common sunflower has C_3 carbon metabolism, but its photosynthetic potential is high, similar to corn (Fock et al. 1979; Potter and Breen 1990). The competitiveness of common sunflower is attributed to its early-season vigor, height, and leaf area (Geier et al. 1996). In Kansas, corn yield loss caused by mixtures of common sunflower and shattercane (*Sorghum bicolor* ssp. Drummondii) populations was predicted with a multiple-species rectangular hyperbola model (Dienes et al. 2004). The model fit pooled data from three of five location-years with a predicted maximum corn yield loss of 60%. Initial slope parameter estimates for common sunflower and shattercane were 49.2 and 4.2%, respectively. A ratio of these estimates indicates that common sunflower was 11 times more competitive than shattercane. Additional published research on the competition of common sunflower in corn does not exist.

Recently, the competitive influence on corn of several broadleaf weed species has been published. Competition of velvetleaf (*Abutilon theophrasti* Medicus) at two plants m^{-2} in corn resulted in a 5% yield reduction and increased to 37% at 21 plants m^{-2} (Werner et al. 2004). It was also shown that corn silage yield reductions were twice that of grain at the low velvetleaf densities. In Ohio, concurrent emergence of corn and giant ragweed (*Ambrosia trifidi* L.) at densities of 1.7, 6.9, and 13.8 weeds per 10 m^2 gave a predicted loss rate of 13.6%

DOI: 10.1614/WT-D-10-00158.1

* First, second, and fourth authors: Former Graduate Research Associate, Graduate Research Associate, and Professor, Department of Soil and Crop Sciences, Texas A&M University, 2474 TAMU, College Station, TX 77843; third author: Professor and Associate Head, Department of Agricultural Economics, Texas A&M University, 2124 TAMU, College Station, TX 77843. Corresponding author's E-mail: cogdillt@tamu.edu

for the first weed per 10 m^2 in the linear response range at low densities and a maximum yield loss of 90% at high weed densities (Harrison et al. 2001). In Kansas, decline in corn forage yield ranged from 1 to 44% of the weed-free yield at Palmer amaranth (*Amaranthus palmeri* S. Wats.) densities of 0.5 and 8 plants m^{-1} of row, whereas decline in grain yield ranged from 11 to 74% of the weed-free yield at the same densities (Rafael and Currie 2002). Steckel and Sprague (2004) reported the critical common waterhemp (*Amaranthus rudis* Sauer)-free period was around the V6 corn stage to optimize corn yield.

The competitiveness of corn with weeds can be enhanced by increasing plant density. Increasing corn density from 4 to 10 plants m^{-2} reduced redroot pigweed (*Amaranthus retroflefus* L.), common lambsquarters (*Chenopodium album* L.), and barnyardgrass (*Echinochla crusgalli* L.) biomass by 50%, whereas corn yield reductions to high weed pressure were 26, 17, and 13% for corn plant densities of 4, 7, and 10 plants m^{-2} (Tollenaar et al. 1994), respectively. Improving the competitiveness of corn with cultural practices can help producers manage weeds. Increasing corn densities with narrow row spacings allowed decreased residual herbicide use rates of atrazine and metolachlor by 75%, yet maintaining adequate weed control (Teasdale 1995). Genetic improvements in corn tolerance to stress and higher planting densities have indicated that plant populations of 37,000 and 47,000 plants ha^{-1} in semiarid regions may be acceptable and provide added weed suppression (Anderson 2004).

In 2002, about 98% of the 32 million ha of corn planted in the United States received an application of a herbicide. The most frequently used herbicides were atrazine, metolachlor, and acetochlor, which were soil-applied PRE compounds (NASS 2002). Before the introduction of sethoxydim-, glyphosate-, and glufosinate-resistant corn, nicosulfuron was the primary POST grass herbicide, and dicamba and atrazine were the predominant POST broadleaf herbicides used in corn (USDA 1998). In an integrated weed management system, the use of PRE herbicide applications are very beneficial. Palmer amaranth that escaped PRE applications of isoxaflutole or flumetsulam caused 13% corn yield loss at a density of 3 plants m^{-1}, whereas corn yield loss from untreated Palmer amaranth at the same density was 30% (Liphadzi and Dille 2006). Velvetleaf that escaped flumetsulam caused 3% corn yield loss at a density of three plants m^{-1}, compared with 38% yield loss caused by untreated velvetleaf at the same density. The introduction of corn varieties resistant to glyphosate shifted herbicide use patterns to more POST applications. A single POST application of glyphosate in corn can be successful, but weed density and herbicide timing are key elements (Myers et al. 2005). Johnson et al. (2000) found that treatments including two herbicide applications tended to provide greater weed control, corn yield, and profit than those with a single application. In total POST treatments, mid-POST applications provided better control than early POST applications on the weeds that germinated throughout the growing season such as shattercane and common cocklebur, but also resulted in yield reductions of up to 23% caused by early-season weed competition. In the northeastern United States, corn growers should apply glyphosate by the V3 to V4 stage to avoid corn yield losses from early-season weed competition in a total POST program (Cox et al. 2006).

Input costs for glyphosate-resistant corn are higher than for nontransgenic hybrids because of technology fees. However, net economic returns are similar and the use of glyphosate POST allows greater flexibility in POST weed management decisions (Johnson et al. 2000). Economic return on investment for various herbicide systems in conventional, imidazolinone-resistant, glufosinate-resistant, and glyphosate-resistant corn hybrids was evaluated in Illinois. There were no differences in economic return in 1999, but in 2000, economic return on investment was greater with the glyphosate-resistant hybrid than with the other hybrids (Nolte and Young 2002). Economic return on investment was influenced more by the grain yield of the corn hybrid than by the associated weed control costs. Werner et al. (2004) found that corn silage yield is more sensitive than corn grain yield to velvetleaf interference and the crop value plays an important role in determining economic thresholds. There is very limited published information regarding the economic impact of specific weeds on the production of corn. Therefore, the objective of this research was to define the economic impact of common sunflower interference in field corn. Components of interference include the impact of common sunflower density and duration of competition on corn, corn density on common sunflower, and herbicide treatment intensity.

Materials and Methods

Field research was conducted at the Texas AgriLife Research Farm, Agronomy Field Laboratory in Burleson County (30°32.262′N, 96°25.818′W), near College Station, TX. The soil was a Ships clay (very-fine, mixed, active, thermic chromic Hapluderts) with pH of 8.1 and soil organic matter of 1.6%. Cultural practices for 2006 and 2007 included two disc-plow tillage operations during the fall before raising the beds for planting. A four-row planter was used to plant hybrid 'DPL 69-71 RR' corn seed on 1-m row spacings to achieve an approximate density of 53,900 plants ha^{-1} on March 24, 2006 and February 26, 2007. Plots consisted of four 6.0-m rows arranged in a randomized complete block design with four replications. Plots were furrow irrigated throughout the season to ensure adequate moisture. Corn grain yield was determined by hand-harvesting 3 m of the two center rows from each treatment. The ear corn was shelled, the grain weighed, and moisture content determined for each plot. The grain weights were adjusted to 15.5% moisture for final grain yield.

Four distinct, but related, experiments were conducted to evaluate the economic consequences of mitigating the damages associated with common sunflower infestation in commercial corn production: common sunflower density effects; corn density effects on common sunflower interference; duration of common sunflower interference; and common sunflower herbicide effectiveness. Descriptions of each of these experiments are presented, followed by statistical and economic analyses of each.

Common Sunflower Density Effects. Treatments consisted of common sunflower densities of 0, one, two, three, four, six, and eight plants per 6 m of crop row. The initial common sunflower stand resulted from a natural population. Common sunflowers 3 to 6 cm tall were covered with foam cups and the plots were sprayed with glyphosate at 0.86 kg ae ha^{-1} to remove unwanted weeds and establish common sunflower densities. Common sunflower densities were established to within 10 cm of the corn row to resemble in-row weeds that escaped cultivation. Common sunflower populations were maintained throughout the growing season with hand and mechanical removal plus applications of glyphosate with a hand-held, single-nozzle, hooded sprayer.

Corn Density Effects on Common Sunflower Interference. A four-row cone-type planter was used to establish plots that represented corn densities of 29,600, 39,500, 49,400, 59,300, and 69,200 plants ha^{-1}. A seed counter was used to obtain the desired densities in each plot with 15% additional seed added to overcome any decreased seed germination and resulting stand reductions. In 2007, two separate studies (2007A and 2007B) involved planting at different locations to replicate the study. Corn seedlings were thinned to the required density at the two-leaf stage. The experiment was arranged in a split-plot design with four replications. The main plots consisted of corn density, whereas the subplots were 0 and 4 common sunflower plants per 5 m of crop row. Mechanical removal or applications of glyphosate were used to maintain common sunflower populations. Common sunflowers were covered with foam cups and the plots were sprayed at the two- to four-leaf corn state with glyphosate at 0.86 kg ae ha^{-1} to remove unwanted weeds and establish common sunflower density.

Duration of Common Sunflower Interference. The experiment was conducted in an area naturally infested with 20 to 25 common sunflower plants m^{-2}. Common sunflower control was maintained by hand hoeing or applying glyphosate at the end of the assigned weed-infested period. Treatments for the weed-infested periods consisted of removal of common sunflower at 0, 2, 4, 6, 8, 12, and 20 wk after emergence. Early applications were made with a tractor-mounted sprayer delivering 0.86 kg ae ha^{-1} glyphosate at 189 L ha^{-1}. At 6 wk after emergence, a CO_2 backpack sprayer delivering 187 L ha^{-1} was used for the remaining glyphosate applications.

Common Sunflower Control in Corn. Plots consisted of four 12-m rows on 1-m spacings in a randomized complete block design with four replications. A 4.6-m alley was provided between replications. PRE treatments were applied immediately after planting and all POST treatments were sprayed when corn was at the V4 to V5 stage. The tractor-mounted sprayer applied herbicide treatments at 187 L ha^{-1} using a 4-m-long boom with eight 11002 flat-fan nozzles (11002, TeeJet Spraying Systems Co, Wheaton, IL) spaced 0.6 m apart. The approximate common sunflower density in treated plots was 20 to 25 plants m^{-2}. The herbicide treatments included (1) atrazine alone at 1.12 kg ai ha^{-1} PRE, (2) atrazine at 1.053 kg ai ha^{-1} plus *S*-metolachlor at 0.806 kg ai ha^{-1} PRE, (3) atrazine at 1.12 kg ha^{-1} PRE followed by (fb) glyphosate at 0.86 kg ae ha^{-1} POST, (4) atrazine at 1.12 kg ha^{-1} PRE fb halosulfuron at 0.036 kg ai ha^{-1} POST, (5) atrazine at 1.12 kg ha^{-1} PRE fb halosulfuron plus nicosulfuron at 0.036 plus 0.036 kg ai ha^{-1} POST, (6) atrazine alone in a 30-cm band at 1.12 kg ha^{-1} PRE, and (7) atrazine in a 30-cm band at 1.12 kg ha^{-1} PRE fb glyphosate at 0.86 kg ha^{-1} POST. Treatments with only POST application included (1) glyphosate alone at 0.86 kg ha^{-1}, (2) halosulfuron alone at 0.036 kg ha^{-1}, (3) nicosulfuron alone at 0.036 kg ha^{-1}, and (4) halosulfuron plus nicolsulfuron at 0.036 plus 0.036 kg ha^{-1}. A 1% v/v crop oil concentrate (Agri-Dex®, nonionic spray adjuvant consisting of a blend of heavy paraffin-based petroleum oil, ployol fatty acid esters, and polyethoxylated derivatives; Helena Chemical Company, Memphis, TN) was added to halosulfuron and nicosulfuron treatments. Corn grain was hand-harvested from 6 m of the two center rows in each treatment. Grain weights were adjusted to 15.5% moisture for final grain yield.

Economic Evaluation. In corn, the economic impact of common sunflower density, duration of competition, corn planting density on competition, and herbicide treatments were determined. In conducting the economic evaluations presented herein, ''net corn price'' refers to gross corn price less harvesting, transportation, and drying costs normally incurred per unit of additional yield. Consequently, producers do not realize the full corn price received in the market, but rather only the residual price remaining after the per-unit costs are paid. Managerial economic decision making should be focused on net marginal consequences of alternatives. Thus, the price range utilized here is expressed as a net of the expected per-unit costs associated with alternative corn yields. Net returns are measured herein in terms of economic returns above specified costs, with the specified costs of concern being the aforementioned per-unit harvesting, transportation, drying costs, plus corn seed cost for planting, herbicide application costs, and cost of herbicide materials when appropriate. Corn seed cost was $1.75 per 1,000 seeds on the basis of $140 per 80,000-seed bag. Herbicide application cost was set at $5 ha^{-1} per application. Herbicide material costs, on the basis of application rates utilized, were $23.47 ha^{-1} for glyphosate, $8.59 ha^{-1} for atrazine, $1.77 ha^{-1} for halosulfuron, $3.69 ha^{-1} for nicosulfuron, and $28.34 ha^{-1} for atrazine plus *S*-metolachlor. All other costs of commercial corn production were ignored, inasmuch as they are virtually constant across strategies and have no effect on the relative ranking of decision alternatives. Net corn prices of $0.08 to $0.24 kg^{-1} are considered, whereas the corn seed price and herbicide and application costs are the marginal cost variables emphasized to determine the economic impacts of various management strategies. All other production costs are established as standard variable and assumed to remain stable with the choice of weed control management strategy. The ultimate goal of this research was to determine the variability of net corn returns resulting from the above variables. The field data for the plant competition experiments were analyzed in Microsoft® Excel using ordinary least-squares (OLS) regression (Neter and Wasserman 1974). Statistical regression and marginal economic analyses were the principal methods used.

Results and Discussion

The focus of projected common sunflower control and management is based on one growing season with no consideration of common sunflower interference in previous or subsequent years. Variability between years can be attributed to differences in environmental conditions that directly affected corn–common sunflower interactions. High temperatures and limited rain with supplemental furrow irrigation to obtain optimum soil moisture occurred in 2006, whereas 2007 had excessive rainfall throughout the season with cooler-than-normal temperatures early in the growing season. In 2006, the rainfall amounts from February through July were 39 cm, whereas in 2007 the rainfall amounts were above 58 cm.

Common Sunflower Density Effects. Impact of common sunflower density on corn yield was examined in 2006 and 2007. Data for the 2 yr were combined using the general functional form of:

$$Y = f(\mathrm{YR,SD}) \quad [1]$$

where Y = corn yield (kg ha^{-1}); YR = 0,1 dichotomous variable for 2006, 2007 year effect (2006 is base 0 and 2007 is 1); and SD = sunflower density (plants per 6 m of crop row). The OLS results were:

$$Y = 13{,}130.4 - 1{,}570.9\mathrm{YR} - 293.0\mathrm{SD}; \quad (37.27),(4.30),(4.19), \quad [2]$$

with the numbers in parentheses representing the respective t statistics for each of the regressed parameters. The adjusted R^2 statistic for the analysis of the 56 observations was 0.38, with an overall F statistic for the regression of 148.0 ($P < 0.0001$). The unexplained variability in yield can be attributed to the differences in environmental conditions between the years. The t statistics indicate that all parameters are significant at $P \leq 0.05$. Regression results showed the maximum yield for 2006 to be 13,130 kg ha^{-1}, with 2007 yields being 1,571 kg ha^{-1} lower and each one sunflower present per 6 m of row accounting for a yield loss of 293 kg ha^{-1}.

On the basis of the above regression results, estimates of the economic losses associated with varying densities of sunflower infestation were calculated for a plausible range of net corn prices (Table 1). The magnitude of losses increases linearly with common sunflower density as well as with the net value of the corn. The extent of the value of yield losses associated with the varying levels of common sunflower infestation ($46 to $368 ha^{-1} for $0.16 kg^{-1} net corn price) suggests that control of common sunflower can be beneficial to corn producers, depending on the costs associated with such management strategies. Even at a net price of $0.08 kg^{-1}, common sunflower control appears worthwhile at higher sunflower densities where estimated losses were $92 ha^{-1} and higher for infestation of four common sunflower plants per 6 m of row and greater.

The information provided in Table 1 allows producers to first determine common sunflower density at a particular location, and then examine the associated economic losses for varying net corn prices. With this information, the producer can be herbicide specific in evaluating application costs and related herbicide efficacy that can be used to project potential net benefits of common sunflower management.

Table 1. Economic losses associated with common sunflower densities at different net corn prices in commercial corn production, College Station, TX, 2006 to 2007.[a]

Common sunflower density[b]	Net corn price[c] (dollars kg^{-1})				
	$0.08	$0.12	$0.16	$0.20	$0.24
Plants (6 m)$^{-1}$	Dollars ha^{-1}				
1	23	35	46	58	69
2	46	69	92	115	138
3	69	104	138	173	207
4	92	138	184	230	276
5	115	173	230	288	345
6	138	207	276	345	414
7	161	242	322	403	483
8	184	276	368	460	553

[a] Corn yield analysis: $Y = 13{,}130.4 - 1{,}570.9\mathrm{YR} - 293.0\mathrm{SD}$; adjusted $R^2 = 0.38$; F statistic for the regression of 148.0. The t statistics are significant at $P \leq 0.05$. No difference between years occurred, so data are pooled for analysis.

[b] Number of common sunflower plants per 6 m of crop row.

[c] Net corn price ranging from $0.08 to $0.24 kg^{-1} equates to $2.00 and $6.00 bu^{-1}. No herbicide applications are considered.

Corn Density Effects on Common Sunflower Interference. Corn yield for various corn planting densities were determined with and without common sunflower interference in 2006 and 2007; two separate field environments were investigated in 2007. The 120 data observations for 2006 and the two 2007 experiments were combined and considered using the general functional form of:

$$Y = f(\mathrm{YRPLOT2007A, YRPLOT2007B, POP, POP^2, POP^3, WEED, POPWEED}) \quad [3]$$

where Y = corn yield (kg ha^{-1}); YRPLOT2007A = 0,1 dichotomous variable for 2006, 2007A year/plot effects (2006 is base 0 and 2007A is 1); YRPLOT2007B = 0,1 dichotomous variable for 2006, 2007B year/plot effects (2006 is base 0 and 2007B is 1); POP = linear term of corn planting density (1,000 seeds ha^{-1}); POP^2 = squared term of corn planting density (1,000 seeds ha^{-1}); POP^3 = cubed term of corn planting density (1,000 seeds ha^{-1}); WEED = 0,1 dichotomous variable for presence of sunflower effects (no sunflowers is base 0 and presence of sunflowers is 1); and POPWEED = interaction term capturing synergy between corn planting density and presence of sunflowers. The OLS results were:

$$Y = 16{,}079.7 - 1{,}804.2\mathrm{YRPLOT2007A} - 1{,}709.5\mathrm{YRPLOT2007B} - 635.1\mathrm{POP} + 16.4\mathrm{POP}^2 - 0.1\mathrm{POP}^3 - 1{,}989.7\mathrm{WEED} + 31.8\mathrm{POPWEED}; (4.07),(11.39),(10.79),(2.40),(2.92),(3.31),(4.27),(3.48), \quad [4]$$

with the numbers in parentheses representing the respective t statistics for each of the regressed parameters. The adjusted R^2

https://doi.org/10.1614/WT-D-10-00158.1 Published online by Cambridge University Press

Table 2. Net returns resulting from competition of common sunflower at different corn densities and different net corn prices in commercial corn production, College Station, TX, 2006 to 2007.[a]

Common sunflower density	Net corn prices	Corn density (× 1,000 plants ha^{-1}) 29.6	39.5	49.4	59.3	69.2
Plants (6 m)$^{-1}$	Dollars kg^{-1}	Dollars ha^{-1}				
2006						
0	$0.08	606	617	655	658	567
	$0.12	934	960	1,025	1,038	911
	$0.16	1,262	1,303	1,395	1,418	1,254
	$0.20	1,590	1,646	1,765	1,799	1,598
	$0.24	1,918	1,989	2,135	2,179	1,942
4	$0.08	522	558	621	649	583
	$0.12	808	872	974	1,025	935
	$0.16	1,094	1,185	1,327	1,400	1,287
	$0.20	1,380	1,499	1,680	1,776	1,638
	$0.24	1,666	1,812	2,033	2,152	1,990
2007 Location A						
0	$0.08	464	476	513	516	425
	$0.12	721	748	812	825	698
	$0.16	978	1,020	1,111	1,135	971
	$0.20	1,236	1,291	1,411	1,444	1,244
	$0.24	1,493	1,563	1,710	1,754	1,517
4	$0.08	380	417	479	507	441
	$0.12	595	659	761	812	722
	$0.16	810	902	1,044	1,117	1,003
	$0.20	1,026	1,144	1,326	1,422	1,284
	$0.24	1,241	1,387	1,608	1,727	1,565
2007 Location B						
0	$0.08	471	483	520	523	433
	$0.12	732	759	823	836	709
	$0.16	993	1,034	1,126	1,150	986
	$0.20	1,254	1,310	1,429	1,463	1,263
	$0.24	1,515	1,586	1,732	1,776	1,539
4	$0.08	387	424	486	514	449
	$0.12	606	670	772	823	733
	$0.16	825	917	1,058	1,132	1,018
	$0.20	1,044	1,163	1,344	1,441	1,303
	$0.24	1,263	1,409	1,630	1,749	1,587
		Cost of common sunflower[b]				
Average across location						
Difference in 0 and 4	$0.08	84	59	34	9	(16)[c]
	$0.12	126	88	51	13	(24)
	$0.16	168	118	68	18	(32)
	$0.20	210	147	85	22	(40)
	$0.24	252	177	102	27	(48)

[a] Corn yield analysis: $Y = 16{,}079.7 - 1{,}804.2\text{YRPLOT2007A} - 1{,}709.4\text{YRPLOT2007B} - 635.1\text{POP} + 16.4\text{POP}^2 - 0.1\ \text{POP}^3 - 1{,}989.7\text{WEED} + 31.8$ POPWEED; adjusted $R^2 = 0.70$; F statistic for the regression of 40.6. The t statistics are significant at $P \leq 0.05$.

[b] Difference in economic returns between 0 and 4 common sunflower that result in the cost of common sunflower infestation.

[c] Parentheses represents net increase.

statistic for the analysis of the 120 observations was 0.70, with an overall F statistic for the regression of 40.6 ($P < 0.0001$). The t statistics indicate that all parameters are significant at $P \leq 0.05$. Regression results show that the maximum yield for 2006 was 16,080 kg ha^{-1}, with the 2007A and 2007B yields being 1,800 and 1,700 kg ha^{-1} lower, respectively. The cubic form of the POP corn planting density variable appears valid, with the statistically significant linear, squared, and cubed parameters being −635.073, +16.370, and −0.126, respectively. The cubic form of the relationship suggests that the highest planting rate included in the experiment of 69,200 plants ha^{-1} was sufficient to result in a yield decrease as a result of excessive competition for moisture or nutrients. The presence of sunflowers (WEED = 1) must be evaluated within the context of the corn planting density (POP) inasmuch as the POPWEED interactive term is significant. Consideration of the first derivative of:

$$-1{,}989.7\text{WEED} + 31.8\text{POPWEED} \qquad [5]$$

calculated with respect to WEED indicates that yields were 1,990 kg ha^{-1} lower in the presence of common sunflower, subject to each 1,000 plants ha^{-1} corn planting density increasing yields by 32 kg ha^{-1}; dividing −1,990 kg ha^{-1} by 32 kg ha^{-1} suggests that a planting density of less than 69,200 plants ha^{-1} will result in corn yields being higher for the weed-free treatments, with the opposite for higher-density

Table 3. Net returns associated with different weeks of competition of common sunflower at different net corn prices in commercial corn production, College Station, TX, 2006.[a]

Weeks of competition[b]	Net corn price (dollars kg^{-1})[c]				
	$0.08	$0.12	$0.16	$0.20	$0.24
Wk	Dollars ha^{-1}				
0	1,015	1,523	2,031	2,539	3,046
1	901	1,351	1,801	2,252	2,702
2	793	1,190	1,587	1,983	2,380
3	693	1,040	1,386	1,733	2,080
4	600	901	1,201	1,501	1,801
5	515	773	1,030	1,288	1,545
6	437	656	874	1,093	1,311
7	366	549	733	916	1,099
8	303	454	606	757	909
9	247	370	494	617	740
10	198	297	396	495	594
11	157	235	313	392	470
12	123	184	245	307	368
13	96	144	192	240	288
14	77	115	153	192	230
15	65	97	129	162	194
16	60	90	120	150	180
17	63	94	125	156	188
18	73	109	145	181	218
19	90	135	180	225	270
20	115	172	229	286	344

[a] Corn yield analysis: $Y = 12{,}924.1 - 1{,}507.2\text{WK} + 46.7\text{WK}^2 - 1{,}523.9\text{YR} + 830.0\text{WKYR} - 31.8\text{WK}^2\text{YR}$; adjusted $R^2 = 0.93$; F statistic was 142.0. The t statistics are significant at $P \leq 0.05$.

[b] Number of weeks common sunflowers were present before removal.

[c] Net corn price ranging from $0.08 to $0.24 kg^{-1} equate to $2.00 and $6.00 bu^{-1}.

Table 4. Net returns associated with different weeks of competition of common sunflower at different net corn prices in commercial corn production, College Station, TX, 2007.[a]

Weeks of competition[b]	Net corn price (dollars kg^{-1})[c]				
	$0.08	$0.12	$0.16	$0.20	$0.24
Wk	Dollars ha^{-1}				
0	896	1,344	1,791	2,239	2,687
1	844	1,266	1,687	2,109	2,531
2	794	1,191	1,588	1,985	2,382
3	747	1,120	1,493	1,867	2,240
4	702	1,052	1,403	1,754	2,105
5	659	988	1,318	1,647	1,977
6	619	928	1,237	1,547	1,856
7	581	871	1,161	1,452	1,742
8	545	818	1,090	1,363	1,635
9	512	768	1,024	1,279	1,535
10	481	721	962	1,202	1,442
11	452	678	904	1,131	1,357
12	426	639	852	1,065	1,278
13	402	603	804	1,005	1,206
14	380	571	761	951	1,141
15	361	542	723	903	1,084
16	344	517	689	861	1,033
17	330	495	660	825	990
18	318	476	635	794	953
19	308	462	616	769	923
20	300	450	601	751	901

[a] Corn yield analysis: $Y = 12{,}924.1 - 1{,}507.2\text{WK} + 46.7\text{WK}^2 - 1{,}523.9\text{YR} + 830.1\text{WKYR} - 31.8\text{WK}^2\text{YR}$; adjusted $R^2 = 0.93$; F statistic was 142.0. The t statistics are significant at $P \leq 0.05$.

[b] Number of weeks common sunflowers were present before removal.

[c] Net corn price ranging from $0.08 to $0.24 kg^{-1} equate to $2.00 and $6.00 bu^{-1}.

plantings. Lower corn-planting densities of 29,600 and 39,500 plants ha^{-1} showed that common sunflowers reduced yields because of interspecific competition. When corn densities reached 69,200 plants ha^{-1}, the overall corn yield decreased because of intraspecific competition, resulting in lower net returns. Corn planting densities from 49,400 to 69,200 plants ha^{-1} revealed minimal impact of common sunflower competition due to the higher densities shading out the common sunflowers. Alternative functional forms involving interaction of the YRPLOT variables with WEED and POPWEED were considered, but the *t* statistics for the added terms were statistically insignificant and those results were discarded.

On the basis of the above regression results, estimates of the expected net returns above harvesting, transportation, drying expenses, and seed corn costs associated with varying corn planting densities were calculated for 2006 and each of the two locations in 2007 using a plausible range of net corn prices (Table 2). Within each year, returns increased for all planting density levels and weed/no weed combinations with increases in the net value of the corn. Also, returns were higher for weed-free scenarios than when weeds were present. The returns increased at each corn planting density through the 59,300 plants ha^{-1} level and then declined at 69,200 plants ha^{-1}. As a result of the linear nature of the dichotomous 0,1 terms for YRPLOTA and YRPLOTB, and the lack of interaction of these terms with the other variables, the differences between the weed-free and the presence of weeds for all three data sets were the same (refer to the bottom of Table 2). As expected, the calculated differences were higher for higher net corn prices. The mitigating effects of the higher corn planting densities reduced the differences in returns at the 69,200 plants ha^{-1} density.

Economic analysis shows that optimizing corn planting density can enhance net profits, with respect to affecting corn yield in both weed-free fields and fields with weeds. For example, in 2006 when corn planting densities were at 59,300 plants ha^{-1} and corn prices were $0.24 kg^{-1}, the net returns were $2,179 ha^{-1} for weed-free and $2,152 ha^{-1} with weeds present. The presence of common sunflower reduced net returns by only $27 ha^{-1} (Table 2). However, at the corn planting density of 29,600 plants ha^{-1}, the presence of common sunflowers resulted in losses of $252 ha^{-1} with corn prices of $0.24 kg^{-1}. Increasing corn planting density to 69,200 plants ha^{-1} caused a decrease in net returns when compared with the planting densities of 49,400 and 59,300 plants ha^{-1}. The presence of common sunflowers in the high corn density of 69,200 plants ha^{-1} did not affect yield because of intraspecific competition. Planting density has a direct impact on net returns and losses due to common sunflower competition, and data suggest that herbicide treatments may be a necessity to achieve maximum net returns. This information allows producers to predict the impact of common sunflowers at various corn planting densities and determine if herbicide applications would be cost effective at different net corn prices.

Table 5. Net returns of selected herbicide applications for common sunflower control in commercial corn production, College Station, TX, 2006 to 2007.

Herbicide[a]	Rate[b]	Timing[c]	2006[d]	2007[d]
	ae or ai kg ha^{-1}		Dollars ha^{-1}	
Nontreated	-	-	609 c	653 d
Atrazine broadcast	1.12	PRE	1,807 a	1,814 ab
Atrazine +	1.053	PRE	1,410 ab	1,436 bc
S-metolachor	0.806	PRE		
Atrazine broadcast fb	1.12	PRE	1,906 a	1,938 a
glyphosate	0.86	POST		
Atrazine broadcast fb	1.12	PRE	1,563 ab	1,888 a
halosulfuron	0.036	POST		
Atrazine broadcast fb	1.12	PRE	1,701 ab	1,791 ab
halosulfuron +	0.036	POST		
nicosulfuron	0.036	POST		
Atrazine banded[e]	1.12	PRE	1,249 b	1,526 abc
Atrazine banded fb	1.12	PRE	1,679 ab	1,880 a
glyphosate	0.86	POST		
Halosulfuron	0.036	POST	1,592 ab	1,602 abc
Halosulfuron +	0.036	POST	1,396 ab	1,721 ab
nicosulfuron	0.036	POST		
Glyphosate	0.86	POST	1,542 ab	1,649 abc
Nicosulfuron	0.036	POST	1,202 b	1,212 c

[a] +, tank mix; fb, followed by.

[b] Rates of herbicides are based upon labeled rates for specific soil characteristics.

[c] V4 to V5 corn.

[d] Means within columns followed by different letters are significantly different at $P \leq 0.05$.

[e] Atrazine banded was applied in a 30-cm band centered over the crop row.

Duration of Common Sunflower Interference. The consequences of common sunflower interference duration on corn yields were examined over the first 20 wk of production in 2006 and 2007. The 56 data observations for the 2006 and 2007 experiments were combined and considered using the general functional form of:

$$Y = f\left(\text{WK}, \text{WK}^2, \text{YR}, \text{WKYR}, \text{WK}^2\text{YR}\right) \qquad [6]$$

where Y = corn yield (kg ha^{-1}); WK = continuous variable representing weeks of sunflower weed presence; WK^2 = squared term of continuous variable representing weeks of sunflower weed presence; YR = 0,1 dichotomous variable for 2006, 2007 year effect (2006 is base 0 and 2007 is 1); WKYR = simple linear interaction of WK and YR effects; and WK^{2}YR = interaction of squared WK and YR linear effects. The OLS results were:

$$Y = 12{,}924.1 - 1{,}507.2\text{WK} + 46.7\text{WK}^2 - 1{,}523.9\text{YR} + 829.9\text{WKYR} - 31.8\text{WK}^2\text{YR}; (34.14), (15.40), (10.06), (2.85), (6.00), (4.84), \qquad [7]$$

with the numbers in parentheses representing the respective t statistics for each of the regressed parameters. The adjusted R^2 statistic was 0.93, with an overall F statistic for the regression of 142.0 ($P < 0.0001$). The t statistics indicate that all parameters are significant at $P \leq 0.05$. Regression showed that the base level of yield for 2006 is 12,924 kg ha^{-1}, with the effects of weeks of sunflower interference and year represented by the other terms. The linear and quadratic forms of the WK variable represent a declining level of yields as the duration of common sunflower competition increased. The significance of the WKYR and WK^{2}YR terms account for the interaction between duration of common sunflower presence and the second year of the experiment.

On the basis of the above regression results, estimates of the expected net returns above harvesting, transportation, and drying expenses associated with varying durations of sunflower competition were calculated for 2006 and 2007, using a plausible range of net corn prices (Tables 3 and 4). For each additional week of common sunflower competition, there was a decrease in net returns, but at a decreasing rate, for all net corn prices. The marginal decrease in net returns are most severe during early season, particularly in 2006. In 2006, net corn returns declined at a faster rate during the early season than in 2007 because of the hot temperatures and limited rainfall.

Determining the duration of common sunflower interference allows producers to use this information to apply herbicides at the most beneficial time and to determine corn revenue losses at other application times. For example, in 2006, when net corn prices were \$0.16 kg^{-1} and common sunflower was allowed to compete for 4 and 8 wk, the net losses were \$830 and \$1,425 ha^{-1}, respectively. Likewise, in 2007, net losses for the same durations of competition were \$388 and \$701 ha^{-1}, respectively. Marginal losses were incurred for each additional week that common sunflower infestations were tolerated. Early-season competition reduced net returns at substantially higher rates than later in the season, suggesting that early-season weed control is crucial in maintaining or increasing net corn returns (Johnson et al. 2000).

Common Sunflower Control in Corn. Prior experiments discussed economic consequences of sunflower infestations in commercial corn production. The economic losses are of

https://doi.org/10.1614/WT-D-10-00158.1 Published online by Cambridge University Press

sufficient magnitude to investigate potential control costs. Numerous alternative herbicide treatments and combinations are available and were evaluated in 2006 and 2007. Herbicides used, rates, and net returns associated with net $0.20 kg^{-1} corn are reported for each treatment (Table 5). Data were subjected to an ANOVA, and means were separated by Tukey's protected honestly significant difference test ($P \leq 0.05$).

Net returns ranged from $609 ha^{-1} for the untreated to $1,906 ha^{-1} with atrazine PRE plus glyphosate POST in 2006, with similar results in 2007. In 2006 and 2007, all treatments showed higher net returns than the nontreated check. Atrazine PRE and atrazine PRE fb glyphosate POST showed higher net returns than nicosulfuron POST and atrazine PRE banded in 2006. In 2007, atrazine PRE fb glyphosate POST, atrazine PRE fb halosulfuron POST, and atrazine banded fb glyphosate POST showed higher net returns than nicosulfuron POST and the premix of atrazine plus *S*-metolachlor PRE. These projected net returns show that several control options are available for the control of common sunflower while providing similar net returns. The net returns from the various herbicide treatments can be used to project the potential net benefits of common sunflower management.

Acknowledgments

The assistance of Andrew Leidner, doctoral graduate student in the Department of Agricultural Economics, and Dr. Michael Longnecker, Professor and Associate Head in the Department of Statistics, both at Texas A&M University, College Station, TX, in conducting and evaluating, respectively, the Tukey's analyses of the herbicide ranking experiment is gratefully acknowledged.

Literature Cited

Anderson, R. L. 2000. Cultural systems to aid weed management in semiarid corn (*Zea mays*). Weed Technol. 14:630–634.

Cox, W. J., R. R. Hahn, and P. J. Stachowski. 2006. Time of weed removal with glyphosate affects corn growth and yield components. Agron. J. 98:349–353.

Dienes, S. R., J. A. Dille, E. L. Blinka, D. L. Regehr, and S. A. Staggenborg. 2004. Common sunflower (*Helianthus annuus*) and shattercane (*Sorghum bicolor*) interference in corn. Weed Sci. 52:976–983.

Fock, H., K. Klug, and D. T. Canvin. 1979. Effect of carbon dioxide and temperature on photosynthetic CO_2 uptake and photorespiratory CO_2 evolution in sunflower leaves. Planta 145:219–223.

Geier, P. W., L. D. Maddux, L. J. Moshier, and P. W. Stalman. 1996. Common sunflower (*Helianthus annuus*) interference in soybean (*Glycine max*). Weed Technol. 16:787–791.

Harrison, S. K., E. E. Regnier, J. T. Schmoll, and J. E. Webb. 2001. Competition and fecundity of giant ragweed in corn. Weed Sci. 49:224–229.

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

Johnson, W. G., P. R. Bradley, S. E. Hart, M. L. Buesinger, and R. E. Massey. 2000. Efficacy and economics of weed management in glyphosate-resistant corn. Weed Technol. 14:57–65.

Liphadzi, K. B. and J. A. Dille. 2006. Annual weed competitiveness as affected by preemergence herbicide in corn. Weed Sci. 54:156–165.

Myers, M. W., W. S. Curran, M. J. Vangessel, T. A. Majek, B. A. Scott, D. A. Mortensen, D. D. Calvin, H. D. Karsten, and G. W. Roth. 2005. The effect of weed density and application timing on weed control and corn grain yield. Weed Technol. 19:102–107.

[NASS] National Agricultural Chemical Statistics Service. 2002. Agricultural Chemical Usage. Washington, DC: Agricultural Statistics Board and USDA, EPA-733-R-02-001.

Neter, S. and W. Wasserman. 1974. Applied Linear Statistical Models. Homewood, IL: Richard D. Irwin.

Nolte, S. A. and B. G. Young. 2002. Efficacy and economic return on investment for conventional and herbicide-resistant corn (*Zea mays*). Weed Technol. 16:371–378.

Potter, J. R. and P. J. Breen. 1980. Maintenance of high photosynthetic rates during the accumulation of high leaf starch levels in sunflower and soybean. Plant Physiol. 66:526–531.

Rafael, A. M. and R. S. Currie. 2002. Impact of Palmer amaranth (*Amaranthus palmeri*) on corn grain yield and yield and quality of forage. Weed Technol. 16:532–536.

Steckel, L. E. and C. L. Sprague. 2004. Common waterhemp (*Amaranthus rudis*) interference in corn. Weed Sci. 52:359–364.

Teasdale, J. R. 1995. Influence of narrow row/high populations on weed control and light transmission. Weed Technol. 9:113–118.

Tollenarr, M., A. A. Dibo, A. Aguilera, S. F. Weise, and C. J. Swanton. 1994. Effect of crop density on weed interference in maize. Agron. J. 86:591–595.

USDA. 1998. Missouri Farm Facts. Washington, DC: U.S. Department of Agriculture Statistical Reporting Service. 62 p.

Werner, E. L., W. S. Curran, J. K. Harper, G. W. Roth, and D. P. Knievel. 2004. Velvetleaf (*Abutilon theophrasti*) interference and seed production in corn silage and grain. Weed Technol. 18:779–783.

Received November 18, 2010, and approved September 30, 2011.