INTERSPECIFIC AND INTRASPECIFIC COMPETITION OF COMMON SUNFLOWER (*Helianthus annuus* L.) IN FIELD CORN (*Zea mays* L.)

A Dissertation

by

NYLAND RAY FALKENBERG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2009

Major Subject: Agronomy

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May 2009

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ABSTRACT

Interspecific and IntraSpecific Competition of Common Sunflower

(*Helianthus annuus* L.) in Field Corn (*Zea mays* L.). (May 2009)

Nyland Ray Falkenberg, B.S., Texas A&M University-Kingsville;

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Common sunflower is a competitive annual native dicot found in disturbed areas, on roadsides, dry prairies, and in row crops. Common sunflower is a competitive weed, but little data exist on interference, economic impacts, and competition in field corn. Field studies were conducted in 2006 and 2007 to 1) define the density-dependent effects of common sunflower competition with corn; 2) define the necessary weed-free periods of common sunflower in corn; 3) evaluate common sunflower control with herbicides; 4) and define the economic impact of common sunflower interference with corn.

Corn grain yield was significantly reduced when common sunflower densities reached 1 plant/m of row and potentitially damaging common sunflower densities occurred if allowed to compete for more than 2 to 4 wk after planting for maximum corn yield. No significant corn yield reduction occurred if common sunflowers emerged 8 wk after planting. Growing degree day (GDD) heat units for corn showed that the critical point for control of common sunflower was approximately 300 GDD. Atrazine applied PRE, atrazine followed by (fb) glyphosate or halosulfuron POST, glyphosate POST, halosulfuron POST, and halosulfuron plus nicosulfuron POST controlled >87% of common sunflower. Atrazine applied PRE in a 30-cm band, nicosulfuron POST, and atrazine broadcast plus *S*-metolachlor PRE showed significantly lower common sunflower control and corn grain yield, when compared to atrazine PRE fb glyphosate POST.

Economic impact of one sunflower/6 m of crop row caused a yield loss of 293 kg/ha. Various corn planting densities showed that corn yield can be reduced 1990 kg/ha with common sunflower competition. Corn planting densities of 49400 and 59300 plants/ha provided the greatest net returns with or without the presence of common sunflower competition. The highest net returns occurred with no common sunflower competition in 2006 and 2007, at $3,046/ha and $2,687/ha, respectively, when net corn prices were $0.24/kg ($6.00/bu). Potential control costs of various herbicide treatments revealed net returns of $1,156 to $1,910/ha in 2006 and $1,158 to $1,943/ha in 2007. Determining the economic impact of common sunflower interference in field corn allows producers to estimate the overall net return based upon density and duration of common sunflower interference, while considering varying net corn prices, crop planting density, and herbicide application costs.

DEDICATION

This dissertation is dedicated to my mom, Janice, and my dad, Leland, for all of the support and opportunities that they provided throughout my life. Without their help I would not be the person, nor in the place, that I am in today. This goal would not have been possible without their support, love, and sacrifices that they have made throughout my life.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to the following people who have made my dissertation research possible:

I would like to thank my committee chair, Dr. Chandler, for his knowledge, support, and guidance and also for allowing me to attend Texas A&M University in order to obtain my Ph.D. I would also like to thank Dr. Cothren for his guidance in the area of plant physiology. I would like to thank Dr. Senseman for his knowledge and guidance on statistics and helping in the preparation of presentations and manuscripts. I would like to thank Dr. Baumann for his expertise in the area of weed science. I would also like to thank Dr. Briske for his knowledge and guidance in his class. I would like to thank Dr. Rister for all the laughs, advice, and his assistance with the economic analysis.

Thanks also go to my friends Sam Willingham, Greg Steele, Weldon Nanson, Mark Humphrey, Grant Walker, Skylar Keesee, and Josh Bynum for making my time at Texas A&M University a great experience.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Common sunflower (*Helianthus annuus* L.) is a member of Asteraceae, one of the largest plant families. This species is an annual native dicot that has existed for over 3,000 years. Common sunflower has a C_3 carbon metabolism, but it's photosynthetic potential is high, similar to maize (Fock et al. 1979; Potter and Breen 1990). It grows in disturbed areas, along roadsides, creek banks, dry prairies, and in fields of numerous row crop species (Irons and Burnside 1982; Geier et al. 1996). Common sunflower is a troublesome weed in much of the north-central United States, Canada, and Mexico due to its morphological variability (Heiser et al. 1969; Miller 1987; Roger et al. 1982).

Common sunflower possesses large and showy flower heads typically 5 to 12 cm wide, with yellow and purplish-brown disk flowers. Large plants can have over 500 heads with each producing up to 600 achenes (nutlets) (Irons and Burnside 1982). When actively growing, the flowers and leaves reorient themselves to the sun to maximize sunlight exposure. The seed are edible by humans and animals, and the plant has been cultivated in pre-Columbian times for seed. Common sunflower blooms from June to October, and frequently inhabits many plant communities at lower elevations but extends up to 1524 m elevations. Root development of common sunflower can be greatly modified as a result of competition with other plants. Common sunflower is one

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This dissertation follows the style of Weed Technology.

of the first species to emerge in early spring with as few as 164 heat units (Buhler et al.1997; Hilgenfeld 2004). Seed can persist in the soil for 3 to 5 yrs before germination (Burnside et al. 1981; Snow et al. 1998). These characteristics and its large stature (1 to 4 m in height) make common sunflower a troublesome weed species (Seiler and Reiseberg 1997).

Farmers must continually manage common sunflower infestations in crops to control them, which requires considerable manual labor, tillage, and herbicides (Eue 1986; Blackshaw et al. 2002). Plant competition from various weeds has show yield reductions in corn (Bendixen 1986; Ghosheh et al. 1996), cotton (*Gossypium hirsutum* L.) (Bridges and Chandler 1987; Keeley and Thullen 1981), sorghum [*Sorghum bicolor* (L.) Moench] (Lopez 1988), soybean (*Glycine max*) (Munger et al. 1987; Dienes et al. 2004; Geier et al. 1996), sugarcane (*Saccharum officinarum* L.) (Ali et al. 1986), onions (*Allium cepa* L.) (Menges 1978), and wheat (*Triticum aestivum*) (Gillespie and Miller 1984). Studies of common sunflower interference in soybeans indicated competition for light (Geier et al. 1996) and production of allelopathic substances (Irons and Burnside, 1982) reducing soybean yield. Weeds compete with field crops for light, nutrients, and water and interfere with harvesting operations and crop quality (Bassett and Munro 1985; Ogg and Rogers 1989). Allelopathy is the release of phytotoxic chemicals by plants into the soil causing adverse effects on other plants (Irons and Burnside 1982). Common sunflower produces larger qualities of phenolics when grown under nutrient stress (Lehman and Rice 1972). Stowe and Osborn (1980) found that phenolics inhibited plant growth only at low nutrient concentrations and indicated that inhibition is likely to occur in nutrient poor soils. Allelopathic agents may be present in, or formed during the decay of leaves, stems, and branches of common sunflower which can reduce the growth and development of sorghum, soybeans, and sunflower (Irons and Burnside 1982). More than one phytotoxic substance in common sunflower water soluble tissue extracts, leaf leachates, and soil exudates suggests that there is an additive effect among toxins, which can affect various plant processes differently (Wilson and Rice 1968).

Competition is defined as the mutally adverse effects of plants that utilize a resource in short supply (Barbour et al. 1987). Interference is the interaction among species, or populations within a species, and is the effect that the presence of a plant has on the alteration in growth rate or form which results from a change in a plants environment due to the presence of another plant (Radosevich et al. 1997). Common sunflower is a competitive weed species, but minimal published research exists on the interference and competitive ability in field corn (Dienes et al. 2004). The competitiveness of common sunflower can be attributed to its early-season growth, height, and leaf area (Geier et al. 1996). Dienes et al. 2004 showed that mixed combinations of shattercane (*Sorghum bicolor* ssp. *Drummondii)* and common sunflower reduced corn yields and was 3.3 times more competitive than shattercane. Research has shown that sugarbeet (*Beta vulgaris* L.) yield was reduced by 70% with common sunflower competition and showed to be fives times more competitive than velvetleaf (*Abutilon theophrasti*) (Schweizer and Bridge 1982). Common sunflower competition in soybean at densities of 4.6 plants/m^2 decreased yields by 95 to 97% (Dienes et al. 2004, Geier et al. 1996), while season-long interference of three common sunflower plants/m^2

reduced soybean yields 47 to 72% (Allen et al. 2000). Common sunflower emerging with soybean had to be removed within 2 weeks after soybean planting and kept weed-free for 4 to 6 weeks to prevent yield losses (Irons and Burnside 1982). The critical period of weed removal is defined as the specific minimum period of time during which the crop must be weed-free to prevent crop yield loss (Zimdahl 1993). Depending on the initial common sunflower densities the critical period ranges between 2 and 8 weeks after soybean planting (Allen et al. 2000; Geier et al. 1996). Onions infested with common sunflower require a weed-free period of 6 weeks to maintain crop quality and prevent yield losses (Menges 1978). One common sunflower plant per m of onion row significantly reduced yield.

The relative competitive ability of field crops may be enhanced by increasing plant density. Increasing corn density from 4 to 10 plants/m^2 reduced redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), and wild mustard [*Brassica kaber* (DC.) L.C.] biomass by 50%, while corn yield reductions attributable 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). Growth and yield of foxtail (*Setaria* spp.) were decreased by 50% with higher levels of corn density (Nieto and Staniforth 1961). Increasing corn density from 3 to 13 plants/m reduced aboveground biomass of yellow nutsedge (*Cyperus esculentus* L.) by 71% (Ghafar and Watson 1983). Johnsongrass (*Sorghum halepense* L.) tillers, aboveground biomass, and interference were reduced by 43% with higher grain sorghum densities (Lopez 1988). Ghosheh et al. (1996) revealed that seedling johnsongrass grown at constant densities of 9.8 plants/m of row did not decrease yields from corn at five different corn planting densities ranging from 29600 to 69200 plants/ha. Improving the competitiveness of corn with cultural practices will help growers manage various weed species. Genetic improvements in corn's tolerance to stressful environments and higher planting densities has indicated that plant populations of 37000 and 47000 plants/ ha in semiarid regions may not be as detrimental as once suggested (Anderson 2000). Increasing corn densities along with narrow-row spacings have decreased residual herbicide use rates of atrazine [6-chlor-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and metolachlor [2-chloro-*N*-(2-ethyl-6-methyl-phenyl)-*N*-(1-methoxypropan-2-yl)acetamide] by 75%, while still controlling weeds effectively (Teasdale 1995).

Adequate control of common sunflower in corn has been difficult to achieve due to ineffective soil-applied herbicides. Few options exist for postemergence control. Postemergence herbicides such as 2,4-D [(2,4-dichlorophenoxy)acetic acid], clopyralid (3,6-dichloro-2-pyridinecarboxylic acid), bromoxynil (3,5-dibromo-4-hydroxybenzonitrile), and bentazon [3-(1-methylethyl)-(1*H*)-2, 1, 3-benzothiadiazin-4(3*H*)-one 2, 2-dioxide] have provided limited success (Al-Khatib et al. 2000). Good common sunflower control has been achieved with chlorimuron [2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid], primisulfuron [2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl] amino]sulfonyl]benzoic acid], nicosulfuron [2-[[[[(4,6-dimethoxy-2-pyrimidinyl) amino]carbonyl] amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide], and thifensulfuron [3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino] carbonyl] amino]sulfonyl-2-

thiophenecarboxylic acid] since the early 1990's (Devlin et al. 1991; Wilson 1993, 1995). Research has shown atrazine plus 2,4-D or atrazine plus dicamba [3,6-dichloro-2-methoxybenzoic acid] provided highest corn yields and greatest common sunflower control; however, atrazine alone resulted in lowest yields and inadequate control (Al-Khatib et al. 2000). In Burleson County, common sunflower control was 98% at 14 and 42 days after treatment (DAT) when atrazine was applied preemergence followed by glufosinate postemergence (Jones et al. 2001). In soybeans, common sunflower control was above 97% from glyphosate [*N*-(phosphonomethyl) glycine] when combined with lactofen [(±)-2-ethoxy-1-methyl-2-oxoethyl-5-[2-chloro-4-(trifluoromethyl)glycine] and acifluorfen [5-[2-chloro-4-(trifluromethyl)phenoxy]-2-nitrobenzoic acid] (Al-Khatib et al. 2000). The only herbicide that showed adequate control was glyphosate with imazethapyr [2-[4,5-dihydro-4-methyl-4-(l-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid]-resistant common sunflower (Al-Khatib et al. 2000). Glyphosate applied sequentially reduced the overall height of common sunflower by 64% and the total plant population by 70 to 74% (Schweizer and Bridge 1982). The utilization of soil-applied herbicides or cultivation in glyphosate-resistant soybeans resulted in 89 to 100% common sunflower control, whereas common sunflower control with glyphosate alone ranged from 39 to 100% (Allen et al. 2000). With multiple glyphosate applications weed densities are low at the end of the season due to early emergence of common sunflower seedlings (Hilgenfeld et al. 2004).

With the introduction of glyphosate-resistant crops (Roundup Ready®) new opportunities were created for the use of this herbicide for selective weed control in crop production (Scursoni et al. 2007). Although glyphosate is the world's most popular herbicide (Magin 2003), and is very effective in controlling many weeds at high densities, specific weeds may escape glyphosate treatment (Scursoni et al. 2007). In glyphosate-resistant corn and cotton, the occurrence of glyphosate-resistance has been confirmed in horseweed (*Conyza canadensis* L.) and Palmer amaranth (*Amaranthus palmeri)* across the southern United States, and its occurrence is increasing (Davis et al. 2007; Culpepper et al. 2006). Monoculture production systems and repeated herbicide use with similar modes of action have led to herbicide resistance in weeds (Peterson 1999; Van Gessel 2001). Therefore, use of management practices to control common sunflower and prevent herbicide resistance are crucial in crop management.

Herbicide resistance in weed species has increased in the last several years with 231 different weed species being reported resistant to specific herbicides (Heap 2001). The ALS-inhibiting herbicides include four chemistry groups including imidazolinones, sulfonylureas, triazolopyrimidines, and pyrimidinyl oxybenzoates (Baumgartner et al. 1999). These herbicides play a major role in ALS resistance which was discovered in common sunflower in Iowa, Kansas, Missouri, and South Dakota (Baumgartner et al. 1999; Heap 2001; White et al. 2002). Al-Khatib et al. (1998) reported that the resistant Kansas common sunflower population was insensitive to imazethapyr. In common sunflower, pollen and seed dispersal play a major role in movement of herbicide resistance (Maxwell and Mortimer 1994) since it is a self-incompatible, insect-pollinated weed (Baumgartner et al. 1999). The reproductive factors of common sunflower increase the likelihood of exchange of genetic material between resistant and susceptible populations (Arias and Rieseberg 1994) along with the physical dispersal of achenes by machinery, water, and animals (Baumgartner et al. 1999; Matthews 1994).

Research has shown common lambsquarters interference in corn resulted in estimates of a single-year economic threshold of 0.3 to 4.2 plants/m of row across the United States (Fischer et al. 2004). Economic threshold levels in soybeans ranged from 0.07 to 0.10 for common sunflower plants/m (Geier et al. 1996). Chandler and Oliver (1979) calculated the economic losses of $11 to $246/A for spurred anoda (*Anoda cristata* L.) competition of various densities and durations in cotton. Mesbah et al. (2004) stated the minimum number of common sunflower plants per m of row that will economically reduce pinto bean yield was 0.12 and 0.2. Determining the economic impacts or economic threshold levels can provide guidance for management strategies to be used by corn producers for the control of common sunflower. However, th effect of common sunflower competition on corn production and the economic impacts involved in various management strategies of this weed are lacking.

Common sunflower is a very problematic weed species in corn, but there is no literature with respect to the competitive interactions between the species. Increased common sunflower density may cause yield reduction; therefore, a better understanding of the critical time period of common sunflowers removal in corn needs to be determined. Tollenaar et al. (1994) stated that the relationship between corn densities and the competitive ability of corn with weeds probably varies with intensity, duration, and timing of weed stress. Because the mechanism of these interactions has not been fully investigated, therefore, the objectives of this research were 1) to define the density-dependent effects of common sunflower competition with corn; 2) to define the weed-infested and necessary weed-free periods of common sunflower in corn; 3) to evaluate common sunflower control with herbicides; 4) and define the economic impacts of common sunflower interference with corn.

CHAPTER II

INFLUENCE OF COMMON SUNFLOWER DENSITY, PERIOD OF COMPETITION AND HERBICIDAL CONTROL ON CORN YIELD

INTRODUCTION

Common sunflower (*Helianthus annuus* L.) is a competitive annual native dicot found in disturbed areas, along roadsides, on dry prairies and in row crops such as corn, soybeans (*Glycine max*), and sorghum [*Sorghum bicolor* (L.) Moench] (Irons and Burnside 1982). Common sunflower can be found in north-central United States, Canada, and Mexico due to its morphological variability (White et al. 2002; Miller 1987; Rogers et al. 1982). Common sunflower is one of the first species to emerge in early spring with as few as 164 heat units (Buhler et al. 1997; Hilgenfeld et al. 2004). Seed can persist in soil for 3 to 5 yrs before germination (Burnside et al. 1981; Snow et al. 1998). These characteristics and its large stature (1 to 4 m tall) make common sunflower a troublesome weed species (Seiler and Reiseberg 1997).

Farmers must continually manage common sunflower infestations for control in crops, requiring considerable manual labor, tillage, and herbicide use (Eue 1986; Blackshaw and Harker 2002). Weeds compete with field crops for light, nutrients, and water and reduce crop quality and interfere with harvesting operations (Bassett and Munro 1985; Ogg and Rogers 1989). Studies of common sunflower interference in soybeans indicated competition for light (Geier et al. 1996) and production of allelopathic substances (Irons and Burnside, 1982) reducing yield. Common sunflower produces larger qualities of phenolics when grown under nutrient stress (Lehman and Rice 1972). Stowe and Osborn (1980) found that phenolics inhibited plant growth only at low nutrient concentrations and indicated that inhibition is likely in nutrient poor soils. Allelopathic agents may be present in, or formed during decay of leaves, stems, and branches of common sunflower which can reduce the growth and development of sorghum, soybeans, and sunflower (Irons and Burnside 1982).

Common sunflower is a competitive weed species, but little data exist on interference and competition in field corn (Dienes et al. 2004). Common sunflower competitiveness can be attributed to its early-season vigor, height, and leaf area (Geier et al. 1996). Dienes et al. 2004 showed that mixtures of shattercane (*Sorghum bicolor* ssp. *Drummondii)* and common sunflower reduced corn yield and was 3.3 times more competitive than shattercane alone. Research showed that sugarbeet (*Beta vulgaris* L.) yield was reduced 70% with common sunflower competition and was five times more competitive than velvetleaf (*Abutilon theophrasti*) (Schweizer and Bridge 1982). Common sunflower interference in soybean at densities of 4.6 plants/m^2 decreased yield 95 to 97% (Dienes et al. 2004, Geier et al. 1996) while season-long interference of three common sunflower plants/m^2 reduced soybean yield 47 to 72% (Allen et al. 2000). Common sunflower emerging with soybean had to be removed within 2 weeks after planting soybean and kept weed free for 4 to 6 weeks to prevent yield loss (Irons and Burnside 1982). The critical period is defined as the specific minimum period of time during which the crop must be weed-free to prevent crop yield loss (Zimdahl 1993). Depending on initial common sunflower densities, the critical period ranges between 2 and 8 weeks after planting in soybean (Allen et al. 2000; Geier et al. 1996). Knowing the critical period of weed control in corn may lead to the use of preventative residual herbicides and well-timed postemergence herbicides.

Control of common sunflower in corn has been difficult to achieve because of ineffective soil-applied herbicides. Few options exist for postemergence control. Postemergence herbicides such as 2,4-D [(2,4-dichlorophenoxy)acetic acid], clopyralid (3,6-dichloro-2-pyridinecarboxylic acid), bromoxynil (3,5-dibromo-4-hydroxybenzonitrile), and bentazon [3-(1-methylethyl)-(1*H*)-2, 1, 3-benzothiadiazin-4-(3*H*)-one 2, 2-dioxide] have provided limited success (Al-Khatib et al. 2000). Good common sunflower control has been achieved with chlorimuron [2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]benzoic acid], primisulfuron [2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl] amino]sulfonyl]benzoic acid], nicosulfuron [2-[[[[(4,6-dimethoxy-2-pyrimidinyl) amino]carbonyl] amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide], and thifensulfuron [3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino] carbonyl] amino]sulfonyl-2-thiophenecarboxylic acid] since the early 1990's (Devlin et al. 1991; Wilson 1993, 1995). Research has shown atrazine [6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] plus 2,4-D or atrazine plus dicamba [3,6-dichloro-2-methoxybenzoic acid] provided highest corn yields and greatest common sunflower control; however, atrazine alone resulted in low corn yields and inadequate control (Al-Khatib et al. 2000). The only herbicide that showed adequate control was glyphosate in imazethapyr [2-[4,5-dihydro-4-methyl-4-(l-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-

pyridinecarboxylic acid]-resistant common sunflower (Al-Khatib et al. 2000). Glyphosate applied sequentially reduced overall height of common sunflower by 64% and total plant population by 70 to 74% (Schweizer and Bridge 1982). Multiple glyphosate applications resulted in low common sunflower densities at the end of the season due to early emergence of common sunflower seedlings (Hilgenfeld et al. 2004).

Although glyphosate is the most popular herbicide globally (Magin 2003), and is very effective in controlling many weeds at high densities, specific weeds may escape glyphosate treatment (Scursoni et al. 2007). In glyphosate-resistant corn and cotton, the occurrence of glyphosate-resistance has been confirmed in horseweed (*Conyza canadensis* L.) and Palmer amaranth (*Amaranthus palmeri)* across the southern United States, and its occurrence is increasing (Davis et al. 2007; Culpepper et al. 2006). Monoculture production systems and repeated herbicide use with similar modes of action have been suggested as the causes for herbicide resistance in weeds (Peterson 1999; Van Gessel 2001). ALS resistance has been discovered in common sunflower in Iowa, Kansas, Missouri, and South Dakota (Baumgartner et al. 1999; Heap 2001; White et al. 2002). In common sunflower, pollen and seed dispersal play a major role in movement of herbicide resistance (Maxwell and Mortimer 1994) since it is a self-incompatible, insect-pollinated weed (Baumgartner et al. 1999). The reproductive factors of common sunflower increase the likelihood of exchange of genetic material between resistant and susceptible populations (Arias and Rieseberg 1994) along with the physical dispersal of achenes by machinery, water, and animals (Baumgartner et al. 1999; Matthews 1994). Therefore, use of management practices to control common sunflower and prevent herbicide resistance are crucial in crop management.

Common sunflower is a very problematic weed species in corn, but there is little literature on the competitive interactions between the species. Because high populations of common sunflower may cause yield reduction in corn, understanding the critical time period of common sunflower removal is essential. Determining the threshold and critical period after crop emergence will provide specific time intervals for herbicide application to reduce yield loss. Further research is needed to determine the relationship between common sunflower and corn. Therefore, the objectives of this research were 1) to define the density-dependent effects of common sunflower competition with corn; 2) to define the weed-infested and necessary weed-free periods of common sunflower in corn; 3) and to evaluate common sunflower control with herbicides.

MATERIALS AND METHODS

General. Experiments were conducted on a Ships clay (Udic Chromustert) soil at the Texas AgriLife Research Farm, Agronomy Field Laboratory in Burleson County, near College Station, TX. Soil pH is 8.1 and soil organic matter is 1.6%. Cultural practices for all years included a two-disc plow tillage operation during the fall before raising the beds for planting. A four-row planter was used to plant hybrid ‘DPL 69-71’ Roundup Ready™ corn seed on 1-m row spacings to achieve an approximate density of 53900 plants/ha on March 24, 2006 and February 26, 2007. Plots consisted of four 6-m rows arranged in a randomized complete block design with four replications. A 2-m alley was provided between replications. Nitrogen was injected in the soil at 64 kg/ha before planting. The trials were watered using furrow irrigation. Corn grain was hand-harvested from 3-m of the two center rows from each treatment. Grain yield was determined after moisture content was adjusted to 15.5%. Data was subjected to an ANOVA, and means were separated by Tukey's protected HSD test ($P \leq 0.05$).

Common sunflower density effects in corn. Treatments consisted of common sunflower densities at 0, 1, 2, 3, 4, 6, and 8 plants/6 m of crop row. Common sunflowers were covered with styrofoam cups and sprayed with glyphosate at 1 kg/ha to remove unwanted weeds and establish common sunflower densities. Common sunflower densities were established to resemble in-row weeds that escaped cultivation. Mechanical removal and glyphosate were used to maintain plots throughout the growing season.

Common sunflower weed-infested period. The experiment was conducted in an area naturally infested with common sunflower with a plot area density of 20 to 25 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, 20 weeks after emergence. Early applications were made with a tractor-mounted sprayer that delivered 187 L/ha using glyphosate applied at the rate of 1 kg/ha. At 6 weeks after emergence a CO_2-backpack sprayer applied water carrier at 187 L/ha for the remaining applications.

Common sunflower weed-free period. Plots were maintained weed-free with applications of glyphosate at a rate of 1 kg/ha 2 to 3 weeks after corn emergence until common sunflower planting. A 1-row vegetable planter was used to plant common sunflower seed 1-cm deep and 6-cm to the side of the corn plant at 0, 1, 2, 4, 6, 8, and 12 weeks after crop emergence. Hand hoeing was used to maintain sunflower densities at 20 to 25 plants/m^2 and prevent the infestation of other weed species. The weed-free trial was irrigated using a linear sprinkler to apply water 3 days after planting common sunflower seeds to enable emergence.

Common sunflower control. Plots consisted of four, 12-m rows and were arranged 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 programs were sprayed when corn was at the V4 to V5 stage (Ritchie et al. 2005) and common sunflower were 8 to 13 cm. The tractor-mounted sprayer applied water carrier at 187 L/ha using a 4-m long boom with eight 11002 flat-fan nozzles[1] spaced 0.6-m apart. The approximate common sunflower density in treated plots was 20 to 25 plants/m^2.

Herbicides being evaluated for common sunflower control in corn were as follow: atrazine applied PRE (30-cm band) at 1.12 kg ai/ha, atrazine PRE at 1.12 kg/ha, atrazine PRE in a (30-cm band) at 1.12 kg/ha fb glyphosate POST at 1.06 kg/ha, atrazine PRE at 1.12 kg/ha fb glyphosate POST at 1.06 kg/ha, glyphosate alone applied POST at 1.06 kg/ha, halosulfuron [[(4,6-dimethoxy -2- pyrimidinyl)amino] carbonyl aminosulfonyl]-3-chloro-1-methyl-1-*H*-pyrazole-4-carboxylate applied POST at 0.036 kg ai/ha, atrazine PRE at 1.12 kg/ha fb halosulfuron applied POST at 0.036 kg/ha. Atrazine PRE at 1.12 kg/ha fb nicosulfuron 2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino] carbonyl]amino] sulfonyl]-*N*,*N*-dimethyl-3-pyridinecarboxamide plus halosulfuron were applied POST at 0.036, 0.036, a premix of atrazine and *S*-metolachlor [2-chloro-*N*-(2-

ethyl-6-methylphenyl)-*N*-[(1*S*)-2-methoxy-1-methylethyl]acetamide] were applied PRE at 1.86 kg ai/ha, and halosulfuron was applied POST at 0.036 kg/ha. A 1% v/v crop oil concentrate[2] was added to halosulfuron and nicosulfuron treatments.

Crop injury (0% = no injury, 100% = crop death) and overall common sunflower control (0% = no injury, 100% = weed death) were visually rated to the nearest 5% as compared with nontreated, weedy control plots. Injury and control ratings were recorded at 14, 28, and 42 d after treatment, respectively. Corn grain was hand-harvested from 6-m of the two center rows in each treatment. Grain yield was determined after moisture content was adjusted to 15.5%. Data was subjected to an ANOVA, and means were separated by Tukey's protected HSD test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Statistical analyses revealed significant year by year interactions; therefore, data were not combined over years. High temperatures and limited rain with supplemental irrigation occurred in 2006, while 2007 had excessive rainfall throughout the season with early, cool-season temperatures. The variability between years can be attributed to the differences in environmental conditions that directly affected corn-common sunflower interactions. Refer to Appendix D for the conversion of tables and figures from the metric to English system.

Common sunflower density effects in corn. Knowledge of the interspecific effects by increasing common sunflower density can provide critical information to understand corn-common sunflower interactions. When compared to the weed-free control significant corn yield reductions occurred when common sunflower densities reached 6 plants/6 m of crop row in 2006 and 2007 (Figure 1). For the densities examined, the lowest corn yield occurred when common sunflower densities reached 8 plants/6 m of crop row. In 2006, corn yield reduction averaged 2, 3, 10, 12, 21, and 30% for common sunflower densities of 1, 2, 3, 4, 6, and 8 plants/6 m of crop row, respectively when compared to the weed-free control. Corn yield reduction averaged 6, 12, 13, 12, 21, and 30% in 2007 for the same densities, and yearly trends were similar.

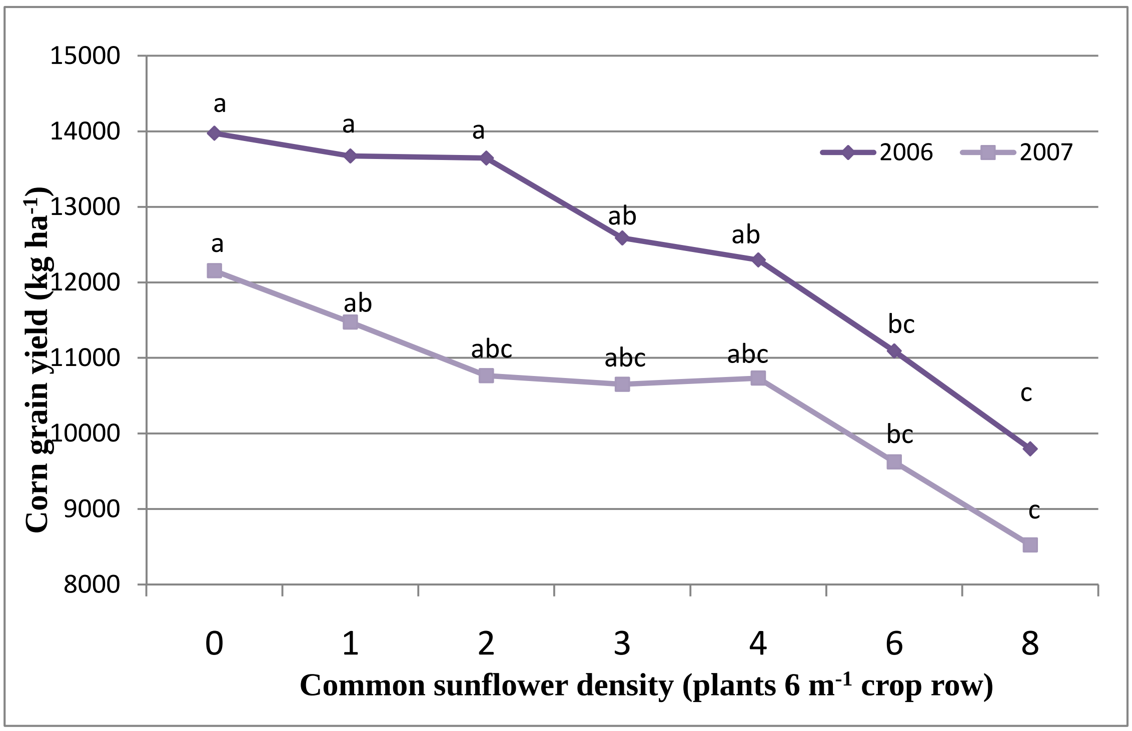

Figure 1. Corn grain yield as affected by common sunflower density in 2006 and 2007. Means within each year were separated using Tukey's Protected HSD test (P≤0.05).

In 2006, corn grain yield declined significantly when common sunflower density increased from 4 to 8 plants/6 m of row. The average corn yield reduction increased from 12 to 30% when common sunflower density was increased from 4 to 8 plants, respectively. Low common sunflower densities of 1 to 4 plants/6 m of row showed no significant corn yield reductions. However, the percent yield loss was ≤13% when compared to the weed-free control. Corn yield reductions indicated aggressive interspecific competition for limited resources when common sunflower densities exceeded 4 plants/6 m of crop row. Therefore, this density can be considered the critical minimum density for implementation of common sunflower control in corn.

Common sunflower weed-infested and weed-free periods. Corn yield was affected by duration of the weed-infested and weed-free periods (20 to 25 common sunflower plants/m^2 in plots) which are shown in Figures 2 and 3. In 2006, the weed-infested period shows common sunflower infestations >2 wks resulted in significant corn yield reduction (Figure 2). Corn yield reduction increased to 8 weeks of infestation until reaching the lowest corn yields at 8 to 20 wks. The weed-free period showed significant corn yield reductions until 8 wks of infestation. The weed-infested and weed-free periods were used to establish the critical period, which can be defined as the period where neither the weed-infested period nor the minimum weed-free period provides unacceptable yield reductions (Ghosheh et al. 1996). Therefore, these data suggest that the critical period is from >3 and <8 wk with the weed-infested period showing significant yield reductions after 2 wk and the weed-free period having no significant differences after 8 wks of common sunflower infestation.

The weed-infested period from 2007 indicated maintaining corn free of common sunflower for 4 weeks following corn emergence resulted in corn yields comparable to

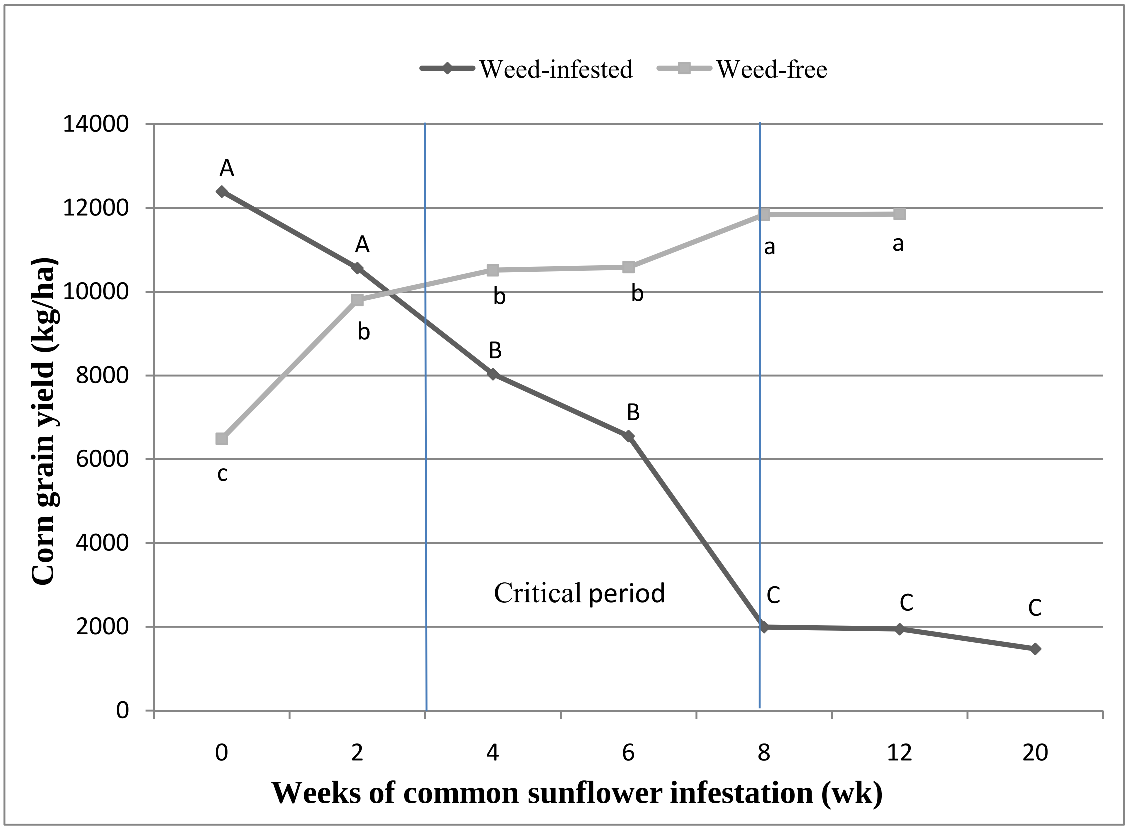

Figure 2. Corn grain yields as affected by increasing durations of common sunflower infestation after planting, maintained either weed-infested or weed-free in 2006. The weed-infested (lower case) and weed-free (upper case) treatments with the same letters for each week of infestation are not significantly different according to the Tukey's Protected HSD test (P≤0.05). The critical period is outined by the lines at 3 and 8 week of infestation.

corn maintained free of common sunflower all season long (20 weeks) (Figure 3). When compared to 2006, the weed-infested period of impact in 2007 was longer which can be attributed to the environmental conditions early in the season that limited plant growth and interspecific competition. The weed-free period in 2007 showed similar results to 2006 with no significant differences in corn yield after 8 wk of infestation. These data show that corn requires weed-free maintenance from common sunflower for 8 wk to avoid significant corn yield reduction. The duration of the critical period of common sunflower control was approximately 5 wk in 2006 and 3 wk in 2007, respectively. Oliver (1988) stated that long critical periods are indicative of a weakly competitive crop or a more competitive weed.

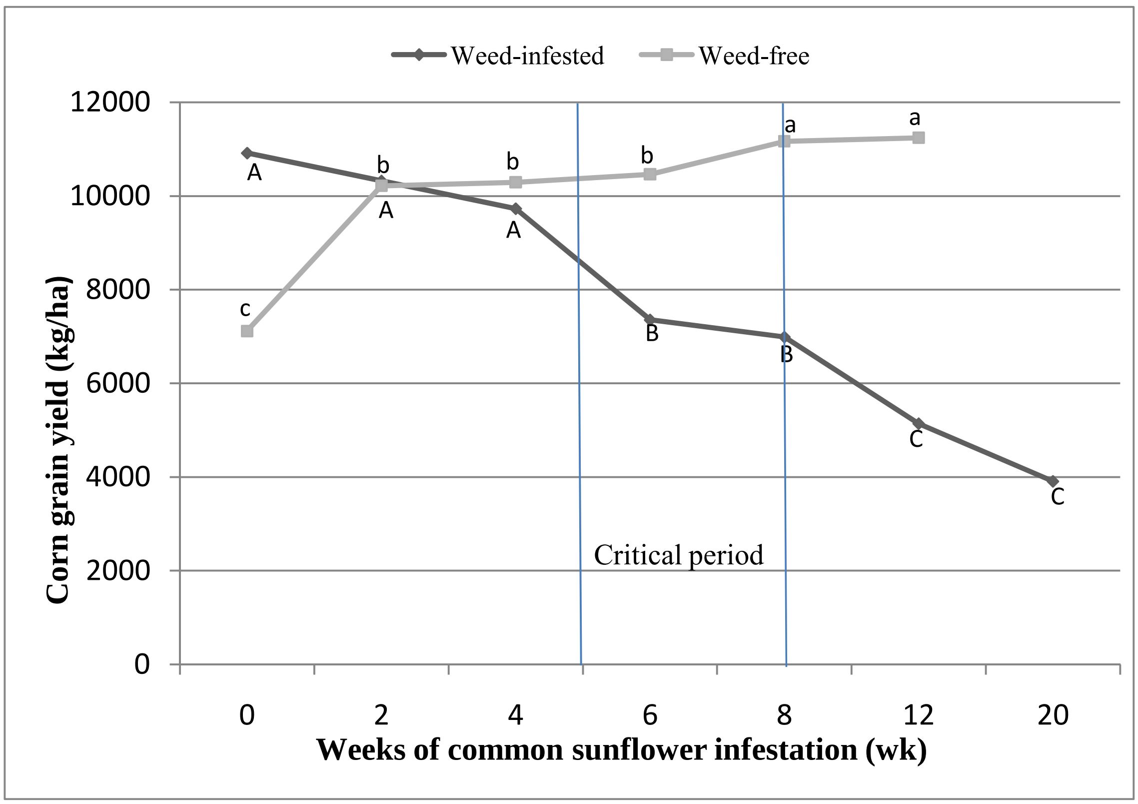

Figure 3. Corn grain yields as affected by increasing durations of common sunflower infestation after planting, maintained either weed-infested or weed-free in 2007. The weed-infested (lower case) and weed-free (upper case) treatments with the same letters for each week of infestation are not significantly different according to the Tukey's Protected HSD test ($P \leq 0.05$). The critical period is outined by the lines at 5 and 8 week of infestation.

Growing degree day (GDD) heat units (McMaster and Wilhelm 1997) for corn were calculated from emergence for both years with common sunflower competition. In

2006, GDD corn heat units were approximately 200, 350, and 480 for 2, 3, and 4 wks of infestation, while in 2007 the heat units were 220, 330, and 400 for 4, 5, and 6 wks of infestations. There were no significant corn yield reductions with GDD corn heat units at approximately 200, while significant corn yield reductions occurred when heat units exceed 400. The point where decline in corn yield was at 3 and 5 wk in 2006 and 2007 began at approximately 300 heat units. This value can serve as the heat unit reference point for control of common sunflower. The ability of common sunflower to intercept sunlight above the crop canopy is an important component in its competitive ability and interference (Geier et al. 1996), and can explain the requirement of GDD heat units for competitive ability with field corn. Mesbah et al. (2004) supported these findings by showing that dry bean production was severely decreased with common sunflower competition due to its rapid, mid-season growth, height, and large leaf size that captures sunlight. The critical removal period in 2006 was >2 wk of infestation due to more interspecific competition occurring early in the season with higher temperatures and plants acquiring more heats units. In 2007, the critical removal period was >4 wk with cool, overcast, and wet conditions early in the season. These conditions limited plant growth and decreased heat units. Furthermore, potentially damaging common sunflower densities exceeding 1 plant/m of crop row should not be allowed to compete with corn for more than 2 to 4 wk depending on the environmental conditions if maximum yield is desired.

Establishing 300 GDD corn heat units as the critical point of common sunflower control in corn can be an alternate management strategy for the varying planting dates and environmental variables which affect producers. These data indicate reducing weed pressure early in the season limited interspecific competition and caused no significant corn yield reduction if common sunflowers emerged after 8 wk. The critical period can be implemented into common sunflower control in corn, with preventative residual herbicides and well-timed POST herbicides. These data indicate that common sunflower control in corn is dependent upon date of planting, GDD corn heat units acquired, and environmental variables.

Common sunflower control. Common sunflower density was approximately 20 to 25 plants/m^2 and control 14 DAT in 2006, showed similar results to 42 DAT. Atrazine PRE showed 87% common sunflower control at 42 DAT. The addition of glyphosate or halosulfuron POST to atrazine increased control to 97% (Table 1). Atrazine applied PRE in a 30-cm band, nicosulfuron POST, and atrazine plus *S*-metolachlor PRE broadcast showed inadequate control (<76%) of common sunflower. However, atrazine PRE (30-cm band) fb glyphosate POST showed 92% control at 42 DAT. All POST treatments of halosulfuron, halosulfuron plus nicosulfuron, and glyphosate showed >92% common sunflower control.

For 2007, common sunflower control showed similar trends to the 2006 data. Atrazine PRE showed 88% control of common sunflower at 42 DAT, which demonstrated significantly higher control than atrazine applied PRE in a 30-cm band, nicosulfuron POST, and atrazine plus *S*-metolachlor PRE. Remaining treatments showed significantly higher control 42 DAT (Table 2). Atrazine banded demonstrated higher

Table 1. Common sunflower control and corn grain yield from different weed-control programs in 2006.

Herbicide[a]	Rate[b]	Timing[c]	Common sunflower 14 DAT[c]	Common sunflower 42 DAT	Grain yield
	kg ai/ha		% control		kg/ha
Non-treated			0 e[d]	0 e	3094 c
Atrazine broadcast	1.12	PRE	86 ab	87 ab	9290 a
fb glyphosate	1.06	POST	95 a	97 a	9976 a
fb halosulfuron	0.036	POST	95 a	97 a	8121 ab
fb halosulfuron + nicosulfuron	0.036 + 0.036	POST	95 a	99 a	8842 ab
Atrazine banded[e]	1.12	PRE	41 d	45 d	6422 b
fb glyphosate	1.06	POST	95 a	92 a	8789 ab
Halosulfuron	0.036	POST	95 a	92 a	8159 ab
+ nicosulfuron	0.036 + 0.036	POST	95 a	94 a	7186 ab
Glyphosate	1.06	POST	95 a	95 a	8018 ab

Table 1. Continued.

Herbicide[a]	Rate [b]	Timing[c]	Common sunflower 14 DAT[c]	Common sunflower 42 DAT	Grain yield
	kg ai/ha		% control		kg/ha
Nicosulfuron	0.036	POST	53 c	57 c	6030 b
Atrazine + *S*-metolachor	1.86	PRE	76 b	76 b	7370 ab

[a] "+", tankmix; fb, followed by.

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

[c] Abbreviations: PRE, preemergence; POST, postemergence (V4 to V5 corn); DAT, days after late postemergence treatment.

[d] Means within columns for each DAT followed by different letters are significantly different at $p \leq 0.05$.

[e] Banded atrazine was applied in a 30-cm band and not over the entire treatable surface.

control than the 2006 season, due to abundant rainfall that activated the herbicide. Atrazine broadcast plus *S*-metolachlor gave lower control in 2007 than 2006, due to the premix atrazine + *S*-metolachlor includes two thirds the recommended rate of atrazine, which also was partially diluted by leaching from the root zone and did not provide season-long common sunflower control. For both growing seasons, atrazine fb POST treatments had numerically higher control than single POST applications. Al-Khatib et al. (2000) supports this data by showing that the greatest reduction in height and control of common sunflower were found with atrazine plus dicamba and atrazine plus 2,4-D. Jones et al. (2001) showed similar results with atrazine PRE fb glufosinate POST controlling 98% of common sunflower, while, glufosinate alone POST provided only 79% control (Jones et al. 2001). Halosulfuron POST showed >92% control of common sunflower during both growing seasons, and efficacy was increased when tank-mixed with nicosulfuron.

Corn yield was higher in herbicide treatments than in non-treated control plots in 2006 and 2007 (Tables 1 and 2). In 2006, corn grain yield ranged from 3094 to 9976 kg/ha (Table 1). The 2006 data show that atrazine broadcast PRE and atrazine broadcast PRE fb glyphosate POST had significantly higher yield than atrazine banded PRE, or nicosulfuron POST. There were no significant yield differences between any of the other treatments. Similar results were obtained in 2007 with corn grain yield ranging from 3318 to 10138 kg/ha (Table 2). Atrazine PRE fb glyphosate POST had significantly higher yield than atrazine banded PRE, atrazine broadcast plus *S*-metolachlor PRE, and nicosulfuron POST. Atrazine PRE, glyphosate POST, halosulfuron POST, and atrazine

Table 2. Common sunflower control and corn grain yield from different weed-control programs in 2007.

Herbicide[a]	Rate[b]	Timing[c]	Common sunflower 14 DAT	Common sunflower 42 DAT	Grain yield
	kg ai/ha		— % control —		— kg/ha —
Non-treated			0 f[d]	0 d	3318 e
Atrazine broadcast	1.12	PRE	88 bc	88 a	9324 abc
fb glyphosate	1.06	POST	100 a	99 a	10138 a
fb halosulfuron	0.036	POST	100 a	99 a	9774 ab
fb halosulfuron+ nicosulfuron	0.036 + 0.036	POST	100 a	99 a	9300 abc
Atrazine banded[e]	1.12	PRE	73 d	70 b	7830 bcd
fb glyphosate	1.06	POST	98 ab	98 a	9811 ab
Halosulfuron	0.036	POST	87 c	96 a	8212 a-d
+ nicosulfuron	0.036 + 0.036	POST	88 bc	99 a	8834 abc
Glyphosate	1.06	POST	98 ab	96 a	8561 abc

Table 2. Continued.

			Common sunflower		
Herbicide[a]	Rate[b]	Timing[c]	14 DAT	42 DAT	Grain yield
	kg ai/ha		— % control —		— kg/ha —
Nicosulfuron	0.036	POST	57 e	62 bc	6241 d
Atrazine + *S*-metolachor	1.86	PRE	57 e	53 c	7505 cd

[a] "+", tankmix; fb, followed by.

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

[c] Abbreviations: DAT, days after late postemergence treatment; PRE, preemergence; POST, postemergence (V4 to V5 corn).

[d] Means within columns for each DAT followed by different letters are significantly different at $p \leq 0.05$.

[e] Banded atrazine was applied in a 30-cm band and not the entire treatable surface.

PRE fb glyphosate or halosulfuron POST broadcast treatments showed no significant differences in corn grain yield for both years. Al-Khatib et al. (2000) showed atrazine broadcast PRE to have the lowest corn grain yield when compared to POST herbicides, which differs from the results of this study.

Halosulfuron POST and glyphosate POST showed no significant differences in percent control of common sunflower and corn grain yield. This indicated that halosulfuron POST or tank-mixed with nicosulfuron POST can be an acceptable substitute for glyphosate in a rotational herbicide management strategy. Atrazine broadcast PRE fb glyphosate POST was considered to be the most effective treatment with significantly higher corn grain yield; however, atrazine broadcast PRE showed no significant differences in weed control and corn grain yield for 2006 and 2007. This suggests that early season common sunflower control is effective in maintaining corn grain yield. Atrazine PRE, glyphosate POST, or halosulfuron POST can be applied in alternate years to prevent herbicide resistance due to these herbicides having different modes of action, and all show no significant differences in common sunflower control or corn grain yield.

Results of these experiments indicate that common sunflower successfully competes with corn. Early removal of common sunflower from crops is crucial in limiting competition and maintaining maximum crop yield (Irons and Burnside 1982). Calculating specific corn heat unit levels can be used to determine the critical growth stage for common sunflower control in corn (McMaster and Wilhelm 1997). Common sunflower are dependent on sunlight and temperature for their competitive ability, therefore, calculating GGD heat units can serve as a primary factor in determing the timing of a biological processe related to the herbicidal control. Implementing PRE herbicide programs can limit early season common sunflower competition in corn, and enable corn to gain a height advantage and reduce sunlight interception by common sunflower. Single POST herbicide applications control common sunflower in corn but do not remove competition early in the season, which may cause reduced corn yields. The results of this study are critical in making effective weed management decisions but do not consider harvest losses or efficiency, corn quality, future weed populations, and application costs. Therefore, these data should be used for competitive thresholds of common sunflower competition in corn.

CHAPTER III

ECONOMIC EVALUATION OF COMMON SUNFLOWER COMPETITION IN FIELD CORN

INTRODUCTION

Weed control is required to sustain and maximize crop production. Plant competition from various weeds has caused yield reductions in corn (Bendixen 1986; Ghosheh et al. 1996). Crop losses due to weeds in major crops in the United States, such as corn (*Zea mays* L.), wheat (*Triticum aestivum*), sorghum [*Sorghum bicolor* (L.) Moench], rice (*Orzya sativa*), and soybean (*Glycine max*) are estimated at 11% to 21% of potential yields. Approximately 82% of the estimated loss occurred in field crops and total estimated losses increased by 4.9 times without herbicide control strategies (Bridges 1992).

Common sunflower, an annual native dicot, is a competitive weed species. However, little published data exists on its interference and competitive ability in field corn (Dienes et al. 2004). The competitiveness of common sunflower is attributed to its early-season vigor, height, and leaf area (Geier et al. 1996). Dienes et al. 2004 showed that mixed combinations of shattercane *(Sorghum bicolor* ssp. *Drummondii)* and common sunflower reduced corn yields, but common sunflower was 3.3 times more competitive than shattercane. Sugarbeet (*Beta vulgaris* L.) yield was reduced 70% by common sunflower competition, which was five times more competitive than velvetleaf (*Abutilon theophrasti*) (Schweizer and Bridges 1982). Common sunflower interference in soybean at densities of 4.6 plants/m^2 decreased yield by 95 to 97% (Dienes et al. 2004, Geier et al. 1996), while season-long interference of three common sunflower plants/m^2 reduced soybean yield 47 to 72% (Allen et al. 2000). Common sunflower emerging with soybean had to be removed within 2 weeks after soybean planting and kept weed free for 4 to 6 weeks to prevent yield losses (Irons and Burnside 1982). Farmers must continously control common sunflower infestations in crops to manage them. Such control requires considerable manual labor, tillage, and herbicides (Eue 1986; Blackshaw et al. 2002).

The relative competitive ability of field crops may be enhanced by increasing or decreasing plant density. Increasing corn density from 4 to 10 plants/m^2 reduced redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), and wild mustard [*Brassica kaber* (DC.) L.C.] biomass by 50%, while possible corn yield reduction 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). Growth and yield of foxtail (*Setaria* spp.) were decreased by 50% with corn densities ranging from 50000 to 60000 plants/ha (Nieto and Staniforth 1961). Increasing corn density from 3 to 13 plants/m reduced aboveground biomass of yellow nutsedge (*Cyperus esculentus* L.) by 71% (Ghafar and Watson 1983). Johnsongrass (*Sorghum halepense* L.) tillers, aboveground biomass, and interference were reduced by 43% with higher grain sorghum densities (Lopez 1988). Ghosheh et al. (1996) reported that seedling johnsongrass grown at constant densities of 9.8 plants/m of row did not decrease corn yields at five different planting densities ranging from 29600 to 69200 plants/ha.

Improving the competitiveness of corn with cultural practices may help growers manage various weed species. Genetic improvements in corn tolerance to stress and higher planting densities have indicated that plant populations of 37000 and 47000 plants/ha in semiarid regions may not be as detrimental to the crop as once suggested (Anderson 2000). Increasing corn densities with narrow-row spacings allowed decreased residual herbicide use rates of atrazine [6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and metolachlor [2-chloro-*N*-(2-ethyl-6-methyl-phenyl)-*N*-(1-methoxypropan-2-yl) acetamide] by 75%, yet maintaining adequate weed control (Teasdale 1995).

Common lambsquarters interference in corn resulted in estimates of a single-year economic threshold of 0.3 to 4.2 plants/m of row for different areas in the United States (Fischer et al. 2004). Economic threshold levels in soybeans ranged from 0.07 to 0.10 for common sunflower plants/m (Geier et al. 1996). Chandler and Oliver (1979) calculated the economic losses of $11 to $246/A for spurred anoda (*Anoda cristata* L.) competition of various densities and durations in cotton. Mesbah et al. (2004) stated that the 0.12 and 0.2 common sunflower plants/m of row will economically reduce pinto bean yield. System costs of various PRE and POST herbicides were evaluated in soybeans for the control of spurred anoda to increase gross returns and showed that intensive hoeing is not economically feasible (Chandler and Oliver 1979).

Swinton and King (1994) showed that the value of information for weed management strategies of dynamic settings can significantly improve expected earnings over a fixed decision rule of examining one source of variability at a time. Determining the economic impacts or economic threshold levels of weeds can provide management strategy guidance for corn producers in common sunflower control. However, information regarding the effects of common sunflower competition on corn production and the economic impacts involved in various management strategies is lacking. Producers are interested in maximizing net economic returns and developing guidelines to determine profitability for common sunflower control in corn. Fluctuating commodity prices provide added incentives for producers to use Best Management Practices (BMP) to minimize economic losses and maximize returns. Tollenaar et al. (1994) stated that the relationship between corn densities and the competitive ability of corn with weeds probably varies with intensity, duration, and timing of weed stress. Therefore, economic evaluations of various corn densities and common sunflower interference needed to be evaluated to determine the effects of interspecific and intraspecific competition for crop yield returns. The objective of this research was to determine the economic impact of common sunflower interference with corn.

MATERIALS AND METHODS

Field research was conducted on a Ships clay (Udic Chromustert) soil at the Texas AgriLife Research Farm, Agronomy Field Laboratory in Burleson County, near College Station, TX. The soil pH was 8.1 and soil organic matter was 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' Roundup Ready™ corn seed on 1-m row spacings to achieve an approximate density of 53900 plants ha^{-1} on March 24, 2006 and February 26, 2007. Plots consisted of four 6-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 and weighing the grain. Grain yield moisture content was adjusted to 15.5%.

Four distinct but related experiments were conducted to evaluate the economic consequences of mitigating the damages associated with sunflower weed 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 at 0, 1, 2, 3, 4, 6, and 8 plants/6 m of crop row. Common sunflowers were covered with styrofoam cups and the plots were sprayed with glyphosate at 1 kg/ha to remove unwanted weeds and establish common sunflower densities. Common sunflower densities were established to resemble in-row weeds that escaped cultivation. Mechanical removal and glyphosate were used to maintain proper common sunflower populations throughout the growing season.

Corn density effects on common sunflower interference. A four-row cone-type planter was used to establish corn densities at 29600, 39500, 49400, 59300, and 69200 plants/ha. Corn seed was counted before planting and 15% additional seed was added to overcome emergence failure and decreased germination. In 2007, two separate studies (2007A and 2007B) were conducted at different locations due to environmental conditions that affected corn emergence. Corn seedlings were thinned to maintain the required density at the 2-leaf stage. The experiment was arranged in a split-plot design with four replications. The main plots consisted of corn density while the subplots were without and with 4 common sunflower plants/4.8 m of crop row. Mechanical removal or applications of glyphosate was used to maintain common sunflower populations. Common sunflowers were covered with styrofoam cups and the plots were sprayed at the 2- to 4-leaf corn stage with glyphosate at 1 kg/ha to remove unwanted weeds and establish common sunflower density.

Duration of common sunflower interference. The experiment was conducted in an area naturally infested with common sunflower with a density of 20 to 25 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 weeks after emergence. Early applications were made with a tractor-mounted sprayer that delivered 187 L/ha using glyphosate applied at the rate of 1 kg/ha. At 6 weeks after emergence, a CO_2-backpack sprayer applied water carrier at 187 L/ha for the remaining applications.

Common sunflower herbicide ranking. Plots consisted of four, 12-m rows and were arranged 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 programs were sprayed when corn was at the V4 to V5 stage. The tractor-mounted sprayer applied water carrier at 187 L/ha using a 4-m long boom with eight 11002 flat-fan nozzles[3] spaced 0.6-m apart. The approximate common sunflower density in treated plots was 20 to 25 plants/m^2.

Herbicides treatments evaluated for common sunflower control in corn were: 1) atrazine applied PRE (30-cm band) at 1.12 kg ai/ha, 2) atrazine PRE broadcast at 1.12 kg/ha, 3) atrazine PRE in a (30-cm band) at 1.12 kg/ha fb glyphosate POST at 1.06 kg/ha, 4) atrazine PRE at 1.12 kg/ha fb glyphosate POST at 1.06 kg/ha, 5) glyphosate alone applied POST at 1.06 kg/ha, halosulfuron [[(4,6-dimethoxy -2-pyrimidinyl)amino] carbonyl aminosulfonyl]-3-chloro-1-methyl-1-*H*-pyrazole-4carboxylate applied POST at 0.036 kg ai/ha, and 6) atrazine PRE at 1.12 kg/ha fb halosulfuron applied POST at 0.036 kg/ha. Atrazine PRE at 1.12 kg/ha fb nicosulfuron 2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino] carbonyl]amino] sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide plus halosulfuron were applied POST at 0.036 kg/ha, a premix of atrazine and *S*-metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-[(1*S*)-2-methoxy-1-methylethyl] acetamide] were applied PRE at 1.86 kg ai/ha, and halosulfuron was applied POST at 0.036 kg/ha. A 1% v/v crop oil concentrate[4] was added to halosulfuron and nicosulfuron treatments. Corn grain was hand-harvested from 6-m of the two center rows in each treatment. Grain yield was determined after moisture content was adjusted to 15.5%.

Economic evaluation. The economic aspects of the various research experiments were examined. Common sunflower density, corn planting density, duration, and herbicidal treatments were used in combination to determine the economic impacts of common sunflower competition in corn. In conducting the economic evaluations presented herein, ‘net corn price’ refers to the recognition of harvesting, hauling/transporting, and drying costs are usually 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 maximizing net marginal returns. Thus, the price range utilized here is expressed as a net of the expected per unit costs associated with alternative corn yields. Economic returns are measured herein in terms of net returns above specified costs, with the specified costs of concern being the aforementioned per unit harvesting, hauling/transporting, corn seed cost for planting, and drying costs plus herbicide materials and application costs. All other costs of commercial corn production are 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 per kg ($2.00 to $6.00/bu) are considered, while 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 variables and assumed to remain stable with the choice of weed control management strategy. Subsequently, statistical and economic methods were identified and utilized to develop economic-oriented information. The ultimate goal of this research was to determine the variability of net corn returns resulting from the above variables. Statistical regression and marginal economic analyses were the principal methods employed.

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. The variability between years can be attributed to the differences in environmental conditions that directly affected corn-common sunflower interactions. High temperatures and limited rain with supplemental irrigation occurred in 2006, while 2007 had excessive rainfall throughout the season with early, cool-season temperatures. In 2006 the rainfall amounts from February through July were 39 cm, while in 2007 the rainfall amounts were above 58 cm. The variability between years can be attributed to the differences in environmental conditions that directly affected corn-common sunflower interactions, due to the variability in temperatures and the timing of rainfall events. Refer to Appendix D for the conversion of tables and figures from the metric to English system.

Common sunflower density effects. Common sunflower density effects on the economic losses in corn were collected in 2006 and 2007. The plot data for this experiment were analyzed in Microsoft® Excel using ordinary least squares (OLS) regression (Neter and Wasserman 1974). Data observations for 2006 and 2007 were combined using the general functional form of:

$$Y = f(Yr, SD) \qquad (1)$$

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

$$Y = 13{,}130.395 - 1{,}570.891\ YR - 293.010\ SD; \quad (37.27), (4.30), (4.19); \qquad (2)$$

with the numbers in parenthases representing the respective t-statistics for each of the regressed parameters. The adjusted R-square statistic for the analysis of the 56 observations was 0.38, with an overall F-statistic for the regression of 148 ($P < 0.0001$). The 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 a P level of ≤ 0.05. Interpretation of the regression results showed the maximum yield for 2006 to be 13,130 kg/ha, with 2007 yields being 1,571 kg/ha lower and each one sunflower present per 6 m of row accounting for a yield loss of 293 kg/ha.

Based on the regression results documented above, estimates of the economic losses associated with varying densities of sunflower infestation were calculated for a plausible range of net corn prices (Table 3). The magnitude of losses increases linearly with the density of infestation as well as with the net value of the corn. The extent of the value of yield losses associated with the varying levels of sunflower infestation (e.g., $46 to $368/ha for $0.16/kg ($4.00/bu) net corn price) are suggestive that mitigation of this weed pest can be beneficial to corn producers, depending on the costs associated with such management strategies. Even at a net price of $0.08/kg ($2.00/bu), economic mitigation appears worthwhile at higher sunflower densities where estimated losses were $92/ha and higher for infestation of 4 common sunflower plants/6 m of row and greater.

The information provided in Table 1 allows producers to (a) first determine the common sunflower density at a particular location, (b) examine the associated economic losses for varying net corn prices, and (c) be herbicide-specific in evaluating the application costs and related herbicide efficacy that can be used to project the potential

Table 3. Economic losses associated with common sunflower densities in commercial corn production, College Station, TX, 2006-2007.[a]

	Net corn price[b]				
	0.08	0.12	0.16	0.20	0.24
Density[c]	Losses in dollars/ha ($/ha)[d]				
0	-	-	-	-	-
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 YR -293.0 SD; adjusted R^2= 0.38; F-statistic for the regression of 148 ($P<0.0001$). The t-statistics are significant at a P level of ≤ 0.05.
No significant difference across years was detected in the statistical analysis so all data are pooled for analysis.
[b] The net corn price ranges from $ 0.08 to $0.24/kg that equated to $2.00 and $6.00/bu. No herbicide applications are considered.
[c] Number of common sunflower plants/6 m of crop row.
[d] Dollar losses/ha for corn due to common sunflower densities at different net corn prices.

net benefits of common sunflower management. Proper weed management decisions can be determined based upon multiple variables, representing a robust decision-making resource.

Corn density effects on common sunflower interference. Economic return of 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 plot data for this experiment were analyzed in Microsoft® Excel using ordinary least squares (OLS) regression (Neter and Wasserman 1974). The 120 data observations for 2006 and the two 2007 experiments were combined and considered using the general functional form of**:**

$$Y = f(YRPLOT2007A, YRPLOT2007B, POP, POP^2, POP^3, WEED, POPWEED) \quad (3)$$

where Y: corn yield (kg/ha); 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); POP^2: squared term of corn planting density (1,000 seeds/ha); POP^3: cubed term of corn planting density (1,000 seeds/ha); 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:

$$Y = 16{,}079.676 - 1{,}804.182\ YRPLOT2007A - 1{,}709.446\ YRPLOT2007B \quad (4)$$
$$-635.073\ POP + 16.370\ POP^2 - 0.126\ POP^3 - 1{,}989.737\ WEED + 31.795\ POPWEED;$$

(4.07), (11.39), (10.79), (2.40), (2.92), (3.31), (4.27), (3.48);

with the numbers in parentheses representing the respective t-statistics for each of the regressed parameters. The adjusted R-square 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 a P level of ≤ 0.05. Interpretation of the regression results is that the maximum yield for 2006 is 16,080 kg/ha, with the 2007 plot A yields being 1,804 kg/ha lower, and the 2007 plot B yields being 1,709 kg/ha lower. The cubic form of the POP corn planting density variable appears valid, with the linear, squared, and cubed parameters being -635.073, +16.370, and -0.126. The cubic form of the relationship suggests that the highest planting rate included in the experiment of 69200 plants/ha was sufficient to result in a yield decrease as a result of excessive competition for moisture and/or fertilizer 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:

$$-1{,}989.737 \text{ WEED} + 31.795 \text{ POPWEED} \qquad (5)$$

calculated with respect to WEED indicates yields were 1,990 kg/ha lower in the presence of weeds, subject to each 1,000 plants/ha corn planting density increasing yields by 32 kg/ha; dividing -1,990 kg/ha by 32 kg/ha suggests that a planting density of less than 69200 plants/ha will result in corn yields being higher for the weed-free treatments, with the opposite for higher density plantings. Lower corn planting densities of 29600 and 39500 plants/ha showed that common sunflowers reduced yields due to interspecific competition. When corn densities reached 69200 plants/ha, the overall corn yield decreased due to high densities causing intra-specific competition and resulting in lower net returns. Corn planting densities from 49400 to 69200 plants/ha revealed minimal impact of common sunflower competition due to the higher densities shading out the common sunflowers, which limited sunlight received by the common sunflowers causing less competition. 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.

Based on the regression results documented above, estimates of the expected economic returns above harvesting, hauling, drying expenses, and seed corn costs associated with varying corn planting densities were calculated for each of the 2006 and the two locations in 2007 (2007A and 2007B) plots using a plausible range of net corn prices (Table 4). As anticipated, returns increase 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 59300 plants/ha level and then decline at 69200 plants/ha. 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 plots were the same (refer to the bottom of Table 4). 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 69200 plants/ha density.

This experiment demonstrates that optimizing corn planting density can enhance net profits, with respect to impacting corn yield in weed-free fields and also as a mitigating factor with weeds. For example, in 2006 when corn planting densities were at 59300 plants/ha and corn prices were $0.24/kg ($6.00/bu), the net returns were $2,179/ha for weed-free and $2,152 with weeds present, revealing that the weed cost was only $27/ha (Table 4). However, at the corn planting density of 29600 plants/ha, the presence of common sunflowers resulted in losses of $252/ha with corn prices of $0.24/kg ($6.00/bu). Increasing corn planting density to 69200 plants/ha showed a decrease in net returns when compared to the planting densities of 49400 and 59300 plants/ha. The presence of common sunflowers in the high corn density of 69200 plants/ ha did not impact yield because of intra-specific 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 economic 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.

Duration of common sunflower interference. The economic consequences of common sunflower interference duration were examined over the first 20 weeks of production in 2006 and 2007. Plot data for this experiment were analyzed in Microsoft® Excel using ordinary least squares (OLS) regression (Neter and Wasserman 1974). The 56 data observations for the 2006 and 2007 experiments were combined and considered using the general functional form of:

Table 4. Gross economic returns associated with different corn density levels and losses resulting from common sunflower plants in commercial corn production, College Station, TX, 2006-2007[a].

		Corn density[b]				
Treatments[c]		29	39	49	59	69
	Net corn prices ($)			2006		
Without weeds				Dollar return/ha		
	$ 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
With weeds[d]						
	$ 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		
Without weeds						
	$ 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

Table 4. Continued.

Treatments[c]	Net corn prices ($)	Corn density[b] 29	39	49	59	69
		2006				
		Dollar return/ha				
With weeds						
	$ 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				
Without weeds						
	$ 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
With weeds						
	$ 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

Table 4. Continued.

Treatments[c]	Net corn prices ($)	Corn density[b]				
		29	39	49	59	69
		Cost of weed[e]				
	$0.08	84	59	34	9	(16)[f]
	$ 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 YRPLOT2007A -1,709.4 YRPLOT2007B -635.1 POP + 16.4 POP^2-0.1 POP^3 -1,989.7 WEED + 31.8 POPWEED; adjusted R^2= 0.70; F- statistic for the regression of 40.6. The t-statistics are significant at a probability level of ≤0.05.
[b] Corn density measured in 1000 plants/ha.
[c] (Without weeds)- no common sunflowers present; (With weeds)-common sunflowers present; (Cost of weed)- losses due to common sunflower interference
[d] Common sunflower density is 4 plants/6 m of crop row.
[e] Losses in dollars/ha.
[f] ( ) represents net increase.

$$Y = f(WK, WK^2, YR, WKYR, WK^2YR) \quad (6)$$

where Y: corn yield (kg/ha); 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^2YR: interaction of squared WK and YR linear effects.

The OLS results were:

$$Y = 12{,}924.089 - 1{,}507.220WK + 46.696\ WK^2 - 1{,}523.869\ YR \qquad (7)$$

$+ 829.969\ WKYR - 31.779\ WK^2YR$; (34.14), (15.40), (10.06), (2.85), (6.00), (4.84); with the numbers in parentheses representing the respective t-statistics for each of the regressed parameters. The adjusted R-square statistic for the analysis of the 56 observations was 0.93, with an overall F-statistic for the regression of 142 ($P< 0.0001$). The t-statistics indicated that all parameters were significant at a P level of ≤ 0.05. Interpretation of the regression results is that the base level of yield for 2006 is 12,924 kg/ha, with the effects of weeks of sunflower interference and year represented by the other terms. The significance of the WKYR and WK^2YR terms account for the interaction between duration of common sunflower presence and the second year of the experiment. The linear and quadratic forms of the WK variable represent a declining, level of returns the longer the duration of sunflower competition.

Based on the regression results documented above, estimates of the expected economic returns above harvesting, hauling, and drying expenses associated with varying lengths of sunflower competition were calculated for each of the 2006 and 2007 plots using a shown at 0 weeks of common sunflower competition in 2006 and 2007. In 2006 and plausible range of net corn prices (Tables 5 and 6). The highest net corn returns were 2007, the highest net corn returns were \$3,046/ha and \$2,687/ha, respectively, when net corn prices were \$0.24/kg (\$6.00/bu). For each week of common sunflower competition, there was a decrease in net corn returns for all net corn prices. In 2006, net corn returns diminished at a higher rate than in 2007 due to the hot

Table 5. Gross economic returns associated with different weeks of competition of common sunflower plants in commercial corn production, College Station, TX, 2006.[a]

	Net corn price ($/kg)[b]				
Weeks of competition (wk)[c]	$ 0.08	$ 0.12	$ 0.16	$ 0.20	$ 0.24
	Dollar return				
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: $Y = 12{,}924.1 - 1{,}507.2WK + 46.7\ WK^2 - 1{,}523.9\ YR + 830.0\ WKYR - 31.8\ WK^2YR$; adjusted $R^2 = 0.93$; F-statistic was 142. The t-statistics are significant at a probability level of ≤ 0.05.
[b] The net corn price ranges from $0.08 to $0.24/kg equating to $2.00 and $6.00/bu.
[c] Number of weeks common sunflowers were present before removal.

Table 6. Gross economic returns associated with different weeks of competition of common sunflower plants in commercial corn production, College Station, TX, 2007.[a]

	Net corn price ($/kg)[b]				
Weeks of competition (wk)[c]	$ 0.08	$ 0.12	$ 0.16	$ 0.20	$ 0.24
	Dollar return				
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: $Y = 12{,}924.1 - 1{,}507.2WK + 46.7\ WK^2 - 1{,}523.9\ YR + 830.1\ WKYR - 31.8\ WK^2YR$; adjusted $R^2 = 0.93$; F-statistic was 142. (significant at the 2.58 E-28 level). The t-statistics are significant at a probability level of ≤ 0.05.
[b] The net corn price ranges from $0.08 to $0.24/kg equating to $2.00 and $6.00/bu.
[c] Number of weeks common sunflowers were present before removal.

temperatures and limited rainfall. The rate of decrease in net corn returns was not as drastic in 2007 due to the cool temperatures and higher comparative rainfall throughout the season.

Determining the duration of common sunflower interference allows producers to use this information to apply herbicides, and to determine corn revenue losses. For example, in 2006 when corn prices were \$0.16/kg (\$4.00/bu) and common sunflower competed for 4 weeks, the net losses were \$830/ha (\$2,031 - \$1,201); however, in 2007 and using the same factors, losses were \$388/ha (\$1,791 - \$1,403). Marginal losses were incurred for each additional week that sunflower weed 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.

Herbicide ranking. Prior experiments discussed economic consequences of sunflower infestations in commercial corn production. The economic losses are of 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 are reported for each treatment (Table 7). Net economic returns above harvesting, hauling, and drying expenses associated with \$ 0.20/ kg (5.00/bu) corn and the cost of each herbicide and application cost are indicated. Data were subjected to an ANOVA, and means were separated by Tukey’s protected HSD test ($P \leq 0.05$).

Net corn yield returns ranged from \$609 for the untreated to \$1911 with atrazine

Table 7. Net returns of various herbicide applications for the control of common sunflower, 2006 and 2007.

Herbicide[a]	Rate[b]	Timing[c]	Net returns[f] 2006	Net returns[f] 2007
	kg ai/ha		Dollars/ha ($/ha)	
Non-treated			609 d[d]	653 d
Atrazine broadcast	1.12	PRE	1807 ab	1814 ab
fb glyphosate	1.06	POST	1911 a	1943 a
fb halosulfuron	0.036	POST	1537 abc	1862 a
fb halosulfuron + nicosulfuron	0.036 + 0.036	POST	1621 abc	1712 ab
Atrazine banded[e]	1.12	PRE	1249 c	1526 abc
fb glyphosate	1.06	POST	1683 abc	1884 a
Halosulfuron	0.036	POST	1565 abc	1576 ab
+ nicosulfuron	0.036 + 0.036	POST	1316 bc	1641 ab
Glyphosate	1.06	POST	1546 abc	1653 ab
Nicosulfuron	0.036	POST	1156 cd	1158 c
Atrazine + *S*-metolachor	1.86	PRE	1410 abc	1436 bc

[a] "+", tank mix; fb, followed by.
[b] Rates of herbicides are based upon labeled rates for specific soil characteristics.
[c] Abbreviations: PRE, preemergence; POST, postemergence (V4 to V5 corn); DAT, days after late postemergence treatment.
[d] Means within columns for each DAT followed by different letters are significantly different at $P \leq 0.05$.
[e] Banded atrazine was applied in a 30-cm band and not the entire treatable surface.

PRE plus glyphosate POST in 2006, with similar results in 2007. In 2006, all treatments except for nicosulfuron POST showed significantly higher net returns than the non-treated check; however, in 2007 all treatments showed significantly higher net returns than the non-treated check. Atrazine PRE fb glyphosate POST showed significantly higher net returns than nicosulfuron POST, atrazine PRE banded, and halosulfuron plus nicosulfuron POST in 2006. The 2007 results showed that atrazine PRE fb glyphosate POST, atrazine PRE fb halosulfuron POST, and atrazine banded fb glyphosate POST showed significantly higher net returns than nicosulfuron POST and the premix of atrazine plus *S*-metolachlor PRE. The net returns from the various herbicides, application costs, and related herbicide efficacy, can be used to project the potential net benefits of common sunflower management.

Data from these experiments demonstrates the importance of making effective weed management decisions. Predicting net corn returns can benefit producers relative to varying net corn prices and management of common sunflower. This information allows producers to determine common sunflower density and duration interference effects and make assessments from to these factors in selecting herbicide, application timing, and the net returns based on the different scenarios.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Common sunflower is a competitive annual native dicot found in disturbed areas, on roadsides, dry prairies, and in row crops. Farmers must continually manage common sunflower infestations in crops, requiring considerable labor, tillage, and herbicide use. Common sunflower is very competitive, but little data exist on interference, economic impacts, and competition in field corn. Research was needed to determine these relationships between common sunflower and corn. Therefore, the objectives of this research were to 1) define the density-dependent effects of common sunflower competition with corn; 2) define the necessary weed-free periods of common sunflower in corn; 3) evaluate common sunflower control with herbicides; 4) and define the economic impacts of common sunflower interference with corn.

Corn yield reductions indicated aggressive interspecific competition for limited resources when common sunflower densities exceeded 4 plants/6 m of crop row. Therefore, this density can be considered the critical minimum density for implementation of common sunflower control in corn. Weed-infestation periods of 3 and 5 weeks after corn emergence for 2006 and 2007, respectively, produced significant corn yield reductions from common sunflower competition. The weed-free period was similar for both years with no reductions in corn yield after 8 wk of common sunflower infestation. The duration of the critical period of common sunflower control in field corn was approximately 5 wk and 3 wk for 2006 and 2007, respectively. Environmental conditions early in the growing season determined the length of the critical period. Growing degree day (GDD) heat units for corn were calculated from emergence for both years. Corn yield showed a rapid decline at 3 and 5 wk when heat units reached 300 due to common sunflower competition. Establishing 300 GDD corn heat units as the critical point of common sunflower control in corn can be an alternate management strategy for the varying planting dates and environmental variables. The critical period can be implemented into common sunflower control in corn, with preventative residual herbicides and well-timed POST herbicides. These data indicate that common sunflower control in corn is dependent upon date of planting, GDD corn heat units acquired, and environmental variables.

Atrazine applied PRE, atrazine followed by (fb) glyphosate or halosulfuron POST, glyphosate POST, halosulfuron POST, and halosulfuron plus nicosulfuron POST controlled >87% of common sunflower. Atrazine applied PRE in a 30-cm band, nicosulfuron POST, and atrazine broadcast plus *S*-metolachlor PRE showed significantly lower common sunflower control (<76%) and corn grain yield, when compared to all other treatments. Using herbicides with various modes of action can successfully control common sunflower and prevent herbicide resistance. Single POST herbicide applications control common sunflower but may not remove competition early enough to prevent reduced corn yields.

Economic impact of one sunflower/6 m of crop row caused a yield loss of 293 kg/ha, while estimated losses at a net corn price of \$0.08/kg (\$2.00/bu) were \$92/ha for infestation levels of 4 common sunflower plants/6 m of row. Various corn planting densities showed that corn yield can be reduced 1990 kg/ha with common sunflower competition. Corn yield was increased by 32 kg/ha by each 1000 plant/ha increase in planting density. Corn planting densities of 49400 and 59300 plants/ha provided the greatest net returns with or without the presence of common sunflower competition. Lower corn planting densities of 29600 and 39500 plants/ha showed that common sunflowers reduced yields due to interspecific competition. When corn densities were 69200 plants/ha, corn yield was decreased due to intra-specific competition and lower net returns.

The highest net returns occurred with no common sunflower competition in 2006 and 2007, at $3,046/ha and $2,687/ha, respectively, when net corn prices were $0.24/kg ($6.00/bu) and planting densites were 59300 plants/ha. Early season competition reduced net returns substantially higher than later in the season, suggesting early season weed control is crucial. Potential control costs for various herbicide treatments revealed net returns of $1,156 to $1,910/ha in 2006 and $1,158 to $1,943/ha in 2007. The net returns from the various herbicides, application costs, and related herbicide efficacy, can be used to project the potential net benefits of common sunflower management.

These experiments provide data for effective weed management decisions. Determining the economic impact of common sunflower interference in field corn allows producers to estimate the overall net return based upon density and duration of common sunflower interference, while considering varying net corn prices, crop planting density, and herbicide application costs.

The results from these experiments illustrate the control and management of common sunflower in corn. It is important that corn producers utilize Best Management Practices (BMPs) to maximize net returns and manage common sunflower. The following guidelines demonstrate how the BMPs can be implemented for the control and management of common sunflower in a corn production scenario. 1) Start with a burndown herbicide or tillage before planting to control the early emerging common sunflower plants. 2) Corn planting densities should be from 49400 to 59300 plants/ha (19400 to 23200 plants/A) to minimize the effects of common sunflower competition and maximize net returns. 3) Apply atrazine preemergence (PRE) since early season control is critical for maximizing net returns. For example, our research indicated when corn prices were \$0.16/kg (\$4.00/bu) and common sunflower competed for 4 weeks, the net losses were \$830/ha (\$330/A). 4) Employ postemergence control measures when common sunflowers densities are more than 4 plants/6 m of crop row (4 plants/18 ft of crop row) and this appears to be the critical minimum density for removal. The research showed that one common sunflower present per 6 m of row accounted for a yield loss of 293 kg/ha or 5 bu/A. 5) The best herbicide program for control of common sunflower was atrazine PRE followed by (fb) an effective postemergence (POST) herbicide. POST programs might include glyphosate or halosulfuron, the latter of which will help prevent glyphosate resistance due to its alternate mode of action. POST applications should be made when common sunflower are 8 to 13 cm (4 to 6 in) tall. 6) Different row widths other than 1 m (40 in) spacings used in this research will alter the planting density of corn alter duration of common sunflower competition due to light interception and competition for resources.

Utilization of these BMPs can assist the corn producers in the management of common sunflower resistance and the maximization of net returns. Corn producers should utilize all these guidelines as part of their management plan for the control of common sunflower.

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APPENDIX A

CLIMATIC CONDITIONS AT TEXAS AGRILIFE RESEARCH FARM NEAR COLLEGE STATION, TX

2006 GROWING SEASON

2006

Date	Air Temperature (°F)		Precipitation (in)	Relative Humidity (%)	
	Max	Min		Max	Min
2/1/2006	20.4	10.8	1.75	100	93
2/2/2006	22.9	11.3	0.01	100	51
2/3/2006	16.2	4.9	0	100	62
2/4/2006	20.1	1.3	0	100	37
2/5/2006	25.2	1.6	0	100	44
2/6/2008	17.5	4	0	100	38
2/7/2006	18.2	-0.6	0	100	37
2/8/2006	22.1	1	0	100	28
2/9/2006	20.6	2.6	0	100	52
2/10/2006	15.9	7	0.77	100	91
2/11/2006	9.7	-0.6	0	100	41
2/12/2006	18	-3	0	100	24
2/13/2006	15.9	-2.4	0	98	23
2/14/2006	23.7	0.9	0	100	48
2/15/2006	23.8	11.4	0	100	75
2/16/2006	26.4	17.5	0	100	73
2/17/2006	19.1	5.6	0.08	100	77
2/18/2006	5.8	0.3	0.03	100	100
2/19/2006	2.5	0.2	0.01	100	100
2/20/2006	6	1.3	0.05	100	100
2/21/2006	12.8	5.8	0	100	100
2/22/2006	20.2	11	0.04	100	100
2/23/2006	21.2	7.8	0	100	46
2/24/2006	15.8	6.7	0	100	68
2/25/2006	14.3	10.9	0.77	100	100
2/26/2006	19.1	4.9	0	100	42
2/27/2006	22.9	3.4	0	100	58
2/28/2006	25.8	9.9	0	100	66
3/1/2006	28.3		0	100	
3/2/2006	27.5	19.2	0	92	61
3/3/2006	25.2	13.2	0	95	34
3/4/2006	23.3	10	0	91	41
3/5/2006	25.2	16	0	99	75
3/6/2006	28.4	16	0	99	49
3/7/2006	26.5	16.2	0	99	70
3/8/2006	28	19.3	0	94	54
3/9/2006	26.3	10	0.13	91	15

3/10/2006	29.6	7.8	0	99	59
3/11/2006	30.2	21.2	0	97	60
3/12/2006	30.3	21.5	0	95	61
3/13/2006	23.9	11	0	93	13
3/14/2006	22.5	6	0	73	17
3/15/2006	20.6	4.9	0	87	30
3/16/2006	24.8	17.1	0	98	76
3/17/2006	21.7	15.6	0	95	33
3/18/2006	20.8	14.5	0.01	96	69
3/19/2006	24.5	17.7	0.12	100	81
3/20/2006	24.1	10.1	1.09	100	36
3/21/2006	18.8	5.9	0	87	41
3/22/2006	14.7	5.2	0	91	61
3/23/2006	11.2	2.9	0.02	95	57
3/24/2006	16.2	-0.2	0	96	36
3/25/2006	21.4	-0.1	0	99	27
3/26/2006	23.6	4.1	0	97	38
3/27/2006	22.3	15.5	0	97	79
3/28/2006	19.6	14.3	1.47	100	86
3/29/2006	22.7	13.9	0.04	100	90
3/30/2006	27.1	18.3	0	98	65
3/31/2006	28.2	18.9	0	100	73
4/1/2006	29.6	21.1	0	99	56
4/2/2006	29.9	20.6	0	98	61
4/3/2006	26.6	18.8	0	99	77
4/4/2006	29.1	15.3	0	94	60
4/5/2006	28.6	19.6	0	98	53
4/6/2006	28.6	19.2	0	98	64
4/7/2006	33.1	16.9	0	95	13
4/8/2006	23.8	11.1	0	92	46
4/9/2006	26.6	8.3	0	97	36
4/10/2006	26.1	9.2	0	98	38
4/11/2006	26.6	12.3	0	97	53
4/12/2006	26.7	14.9	0	99	69
4/13/2006	28.4	17.1	0	99	49
4/14/2006	29.6	14.5	0	99	49
4/15/2006	30.4	19.3	0	95	55
4/16/2006	32.8	21.4	0	94	54
4/17/2006	34.4	20.6	0	98	48
4/18/2006	34.3	19.6	0	99	47
4/19/2006	32.3	19.6	0	96	55
4/20/2006	27	18.7	0.25	98	73

4/21/2006	27.6	17.4	0.37	99	66
4/22/2006	29.8	15.1	0	100	49
4/23/2006	30.4	17.2	0	100	61
4/24/2006	29.4	20.8	0	99	69
4/25/2006	30	14.6	0.31	99	68
4/26/2006	23.7	12.9	0	96	57
4/27/2006	24.6	12.8	0	98	52
4/28/2006	29.9	19.2	0	91	65
4/29/2006	27.1	15.9	0.62	98	46
4/30/2006	30.9	11.5	0	99	22
5/1/2006	32.2	14.1	0	99	50
5/2/2006	31.6	22	0	98	59
5/3/2006	32.1	21.6	0	98	49
5/4/2006	31.2	20.3	0.03	99	63
5/5/2006	31.9	20.3	0.15	98	40
5/6/2006	27.9	17.9	0.83	100	71
5/7/2006	28.9	20.1	0	97	70
5/8/2006	29.9	18.8	0.43	99	71
5/9/2006	33.1	23.6	0	98	71
5/10/2006	32.7	18.5	0	97	50
5/11/2006	27.4	12.1	0	97	23
5/12/2006	29.8	10.5	0	98	24
5/13/2006	32.6	13.7	0	98	44
5/14/2006	25.1	17.4	0.41	99	86
5/15/2006	25.7	14.4	0	100	42
5/16/2006	28.2	11.7	0	98	34
5/17/2006	30	11.7	0	99	29
5/18/2006	33.1	11.7	0	99	27
5/19/2006	35.2	17.3	0	99	32
5/20/2006	32.8	19.9	0	99	41
5/21/2006	32.8	16.1	0	98	40
5/22/2006	33.4	22.3	0	97	43
5/23/2006	32.9	21.4	0	99	51
5/24/2006	34.5	22	0	97	43
5/25/2006	34.7	22.8	0	96	45
5/26/2006	34.4	21.3	0	98	46
5/27/2006	34.9	24.1	0	96	45
5/28/2006	29.4	22.5	0	97	62
5/29/2006	29.3	21.1	0.01	99	61
5/30/2006	29.3	19.7	0	97	71
5/31/2006	24.7	21.4	0.12	98	85
6/1/2006	30.7	21	0.26	99	62

6/2/2006	33.2	18.8	0.01	100	51
6/3/2006	34.1	20.1	0	99	41
6/4/2006	34.5	19.3	0	99	40
6/5/2006	34.5	20.2	0	99	43
6/6/2006	35.3	19.6	0	97	37
6/7/2006	37.6	18.9	0	98	37
6/8/2006	36.3	20.7	0	96	39
6/9/2006	36.9	22.5	0	95	39
6/10/2006	36	20.7	0	95	31
6/11/2006	35.1	19.6	0	99	36
6/12/2006	37.3	18.4	0	97	27
6/13/2006	39	19.4	0	92	33
6/14/2006	35.6	22.2	0	83	25
6/15/2006	35.7	18.6	0	97	36
6/16/2006	31.5	22.8	0.67	98	62
6/17/2006	31	20.3	0.56	99	74
6/18/2006	32.2	21	0.82	99	61
6/19/2006	31	21.7	0	99	63
6/20/2006	28.1	22.5	0.38	100	77
6/21/2006	32.8	22.9	0	99	63
6/22/2006	33.1	23.4	0.3	99	61
6/23/2006	36	21.7	0	99	42
6/24/2006	32.6	22.4	0	99	65
6/25/2006	35.6	22	0	99	42
6/26/2006	33.9	19	0	97	38
6/27/2006	32.6	16	0	97	28
6/28/2006	34.1	16.1	0	97	35
6/29/2006	33.4	18.4	0	97	37
6/30/2006	33.8	19.6	0	96	41
7/1/2006	32.9	21.5	0.06	99	58
7/2/2006	30.1	21.6	0.07	100	74
7/3/2006	30.1	22.2	0	100	73
7/4/2006	27.9	22	1.67	100	88
7/5/2006	29.8	23.1	0.12	99	78
7/6/2006	32.9	22.4	0	99	64
7/7/2006	32.7	22.8	0	99	56
7/8/2006	33.6	23.1	0	98	61
7/9/2006	32.5	23.4	0	99	68
7/10/2006	34	23.3	0	99	56
7/11/2006	35.3	22.8	0	99	52
7/12/2006	34.8	24	0	98	51
7/13/2006	35.4	22.8	0	99	49

7/14/2006	34.5	22.8	0	99	51
7/15/2006	36.4	22.8	0	98	41
7/16/2006	37.1	23.8	0	97	45
7/17/2006	37.3	23.7	0	96	40
7/18/2006	37.3	24.5	0	95	45
7/19/2006	36	22.4	0	98	43
7/20/2006	36.4	24.9	0	96	40
7/21/2006	36.3	22.4	0	98	45
7/22/2006	.	.	.	.	.
7/23/2006	37.2	22.2	0.16	98	37
7/24/2006	33.4	23	0.61	99	59
7/25/2006	31.9	22.8	0	99	65
7/26/2006	29.3	23.4	0.06	99	78
7/27/2006	31	24.5	0	100	72
7/28/2006	34.7	23.9	0	100	53
7/29/2006	35.5	23.4	0	99	52
7/30/2006	35	22.7	0	99	51
7/31/2006	35	23.3	0	99	55
8/1/2006	34.7	23.1	0	99	53
8/2/2006	35	22.6	0	99	54
8/3/2006	36.2	23.5	0	99	41
8/4/2006	37	21.6	0	99	40
8/5/2006	36.1	22.1	0	99	45
8/6/2006	36.1	22.4	0.49	99	46
8/7/2006	30	22.1	2.67	100	80
8/8/2006	34.9	22.7	0	100	55
8/9/2006	35.5	23.2	0	99	51
8/10/2006	36	23.4	0	99	48
8/11/2006	35.6	23.9	0	100	51
8/12/2006	.	.	.	.	.
8/13/2006	35.6	22.9	0	99	46
8/14/2006	36.6	23.2	0	99	43
8/15/2006	38.5	22.2	0	99	36
8/16/2006	37.4	23	0	99	36
8/17/2006	39.3	22.8	0	98	41
8/18/2006	36.9	24.3	0	96	43
8/19/2006	35.2	23.3	0	97	57
8/20/2006	37.9	22.7	0	99	43
8/21/2006	37.1	23	0	98	42
8/22/2006	37.6	22.8	0.12	98	41
8/23/2006	36.5	23.4	0	99	42
8/24/2006	36.9	23.8	0	99	46

8/25/2006	37.7	23.6	0	98	43
8/26/2006	38.2	25.2	0	99	41
8/27/2006	37	24.3	0	99	43
8/28/2006	37.7	25.1	0	98	38
8/29/2006	33.9	23.9	0.01	96	54
8/30/2006	36.4	18.4	0	94	31
8/31/2006	37.5	20.1	0	88	30

APPENDIX B

CLIMATIC CONDITIONS AT TEXAS AGRILIFE RESEARCH FARM NEAR COLLEGE STATION, TX

2007 GROWING SEASON

2007

Date	Air Temperature (°F)		Precipitation (in)	Relative Humidity (%)	
	Max	Min		Max	Min
2/1/2007	11.4	5.5	0.01	100	98
2/2/2007	8.7	0.7	0	100	66
2/3/2007	10.4	-3.2	0	100	57
2/4/2007	19	-0.1	0	100	53
2/5/2007	19.1	1.4	0	100	52
2/6/2007	20.9	2.5	0	100	66
2/7/2007	23.4	7.3	0	100	75
2/8/2007	17.2	8.5	0	100	89
2/9/2007	9.6	6.3	0	100	97
2/10/2007	7.6	5.1	0	100	86
2/11/2007	11.5	6.8	0	100	83
2/12/2007	20.5	11.4	0.04	100	95
2/13/2007	13.8	2.4	0	100	77
2/14/2007	3.8	0.4	0	89	78
2/15/2007	5.2	-4.4	0	98	66
2/16/2007	10.2	-6.9	0	100	52
2/17/2007	17.9	-2.3	0	100	34
2/18/2007	17.3	-3.3	0	100	32
2/19/2007	22.7	2.3	0	100	65
2/20/2007	20.9	15.4	0	100	92
2/21/2007	27.8	10.3	0	100	22
2/22/2007	26.7	9.3	0	100	46
2/23/2007	20.7	14.6	0	100	98
2/24/2007	25.5	12.5	0.01	100	15
2/25/2007	21.6	4.9	0	86	30
2/26/2007	28.4	5.6	0	100	25
2/27/2007	27.1	7	0	100	60
2/28/2007	24.2	18.6	0	100	86
3/1/2007	22	5.9	0.03	100	21
3/2/2007	22.6	2.8	0	97	19
3/3/2007	17	2	0	93	28
3/4/2007	15.9	-3.7	0	92	25
3/5/2007	20.4	-3.7	0	100	24
3/6/2007	21.2	1	0	100	38
3/7/2007	22.9	5	0	100	57
3/8/2007	24	6.2	0	100	54
3/9/2007	26.4	8.4	0	100	59

3/10/2007	28	15.2	0	100	56
3/11/2007	24.5	13.3	0.17	100	62
3/12/2007	23.6	15.7	1.17	100	81
3/13/2007	21.6	14.7	1.54	100	97
3/14/2007	19.2	13.7	1.23	100	100
3/15/2007	26.8	12	0.01	100	71
3/16/2007	20.6	11.1	0	100	77
3/17/2007	22.4	7.3	0	100	67
3/18/2007	23.4	12.4	0	100	81
3/19/2007	25	17.6	0	100	72
3/20/2007	25.5	18	0	100	72
3/21/2007	25.7	18.5	0	100	78
3/22/2007	25.3	18.5	0	100	78
3/23/2007	26.1	18.7	0	100	78
3/24/2007	27.1	17.9	0	100	75
3/25/2007	25.1	18.6	0	100	87
3/26/2007	24.3	16.8	2.18	100	85
3/27/2007	27.5	16.4	0.01	100	79
3/28/2007	27.6	18.5	0	100	76
3/29/2007	25.9	20.4	0	100	87
3/30/2007	24.7	20.6	0	100	85
3/31/2007	24.8	14.6	0.19	100	56
4/1/2007	27.4	10	0	100	48
4/2/2007	27.9	16.9	0	100	82
4/3/2007	28.5	19.9	0	100	81
4/4/2007	22.3	12.1	0.04	100	53
4/5/2007	21.2	10.1	0	100	49
4/6/2007	20.6	10.1	0	100	50
4/7/2007	10.4	1.6	0.54	100	65
4/8/2007	10.3	1.9	0.01	100	74
4/9/2007	16.7	8.7	0	99	75
4/10/2007	25.1	13.6	0.03	100	77
4/11/2007	26.1	12.4	0	100	35
4/12/2007	26.6	9.4	0	100	38
4/13/2007	26.4	14.7	0.16	100	84
4/14/2007	15.2	5.8	0.03	100	80
4/15/2007	23.3	3.6	0	100	43
4/16/2007	22.2	6	0	100	61
4/17/2007	19.1	12.8	0.37	100	93
4/18/2007	20.8	10.6	0	100	85
4/19/2007	25.7	8.7	0	100	69
4/20/2007	25.7	15	0	100	71

4/21/2007	26.8	11.6	0	100	56
4/22/2007	26	17.5	0	100	80
4/23/2007	26.1	19.6	0	100	87
4/24/2007	25	22	0.01	100	88
4/25/2007	26.9	15	1.01	100	54
4/26/2007	25.6	11.2	0	100	58
4/27/2007	24	12.9	0	100	73
4/28/2007	29.6	15.7	0	100	69
4/29/2007	29.7	17.6	0	100	74
4/30/2007	27.7	17.9	0.93	100	70
5/1/2007	24.9	18.3	0.19	100	95
5/2/2007	27.9	17.4	0.93	100	86
5/3/2007	27.4	16.1	0.08	100	90
5/4/2007	28.5	20.3	0	100	93
5/5/2007	30	22.8	0	100	83
5/6/2007	30.4	23.6	0	100	82
5/7/2007	30.8	21.9	0	100	71
5/8/2007	29.4	20.3	0	100	77
5/9/2007	29	18.4	0	100	57
5/10/2007	28.5	16.2	0	100	68
5/11/2007	29.3	16.4	0.07	100	58
5/12/2007	32.1	15.7	0	100	55
5/13/2007	32.1	17.5	0	100	58
5/14/2007	33.6	18	0	100	47
5/15/2007	32.3	17.9	0	100	50
5/16/2007	28.6	17.1	0	100	60
5/17/2007	27.3	13.2	0	100	47
5/18/2007	26.8	14.2	0	100	47
5/19/2007	26.9	13.8	0	100	48
5/20/2007	27.9	14.5	0	100	56
5/21/2007	27.3	17.5	0	100	72
5/22/2007	25.7	18.1	0.54	100	86
5/23/2007	30.8	19.6	0	100	72
5/24/2007	31.3	20.7	0	100	68
5/25/2007	27.3	19	0.31	100	86
5/26/2007	23.5	19.8	0.6	100	100
5/27/2007	25.2	19.4	0.43	100	94
5/28/2007	25.8	19.6	0.28	100	90
5/29/2007	29.3	20.6	0	100	79
5/30/2007	30.5	21.7	0	100	76
5/31/2007	31.4	20.4	0	100	70
6/1/2007	30.9	21.6	0	100	66

6/2/2007	31.9	20.5	0	100	68
6/3/2007	32.5	21	0.08	100	70
6/4/2007	30.9	19.5	0.01	100	67
6/5/2007	31.9	17.8	0	100	58
6/6/2007	31.7	18.5	0	100	74
6/7/2007	33.1	24.6	0	100	77
6/8/2007	34.2	25.7	0	100	70
6/9/2007	33.3	24.9	0	100	69
6/10/2007	33.1	22.5	0	100	70
6/11/2007	33.6	20.8	0	100	66
6/12/2007	33.5	20.4	0	100	64
6/13/2007	34.9	21	0.98	100	61
6/14/2007	33.3	20.5	0.06	100	68
6/15/2007	30.8	20.1	0.09	100	82
6/16/2007	29	22.3	0.15	100	91
6/17/2007	28.3	20.8	1.68	100	92
6/18/2007	33.4	23.2	0	100	72
6/19/2007	34.1	25.7	0	100	72
6/20/2007	30.5	22	0	100	88
6/21/2007	31.5	23.4	0	100	72
6/22/2007	30.3	22.1	0.06	100	87
6/23/2007	30	21.7	0.01	100	76
6/24/2007	30.5	21.6	0	100	80
6/25/2007	29.8	21.7	0.72	100	90
6/26/2007	32	23.7	0.17	100	75
6/27/2007	31.8	23.1	0	100	78
6/28/2007	31.6	21.7	0.68	100	79
6/29/2007	31.8	21.5	0.37	100	81
6/30/2007	32.4	22.4	0.49	100	79
7/1/2007	29.8	22.9	0.9	100	90
7/2/2007	29	22.5	0.08	100	87
7/3/2007	31.1	22.8	0	100	80
7/4/2007	27.8	22.9	0.07	100	91
7/5/2007	28.1	22.6	0.1	100	91
7/6/2007	32	23.4	0.1	100	80
7/7/2007	32.6	22.2	0	100	73
7/8/2007	32.4	22.1	0.22	100	78
7/9/2007	33	25.1	0	100	76
7/10/2007	34	22.9	0	100	71
7/11/2007	33.9	21.9	0	100	67
7/12/2007	34.7	24	0	100	71
7/13/2007	32.5	22.7	0	100	77

7/14/2007	32.1	23.6	0.56	100	80
7/15/2007	31.2	21.3	0.09	100	83
7/16/2007	32.4	20.7	0	100	71
7/17/2007	32.7	21.9	0	100	71
7/18/2007	30.6	21.8	0	100	74
7/19/2007	29.5	21.7	0.45	100	93
7/20/2007	27.4	21.9	1.15	100	94
7/21/2007	31.7	22.1	0	100	81
7/22/2007	34.2	21.4	0.12	100	69
7/23/2007	33	22.4	0	100	71
7/24/2007	31.3	19.5	0	100	58
7/25/2007	31.6	20.6	0.2	100	75
7/26/2007	30.8	22.1	0.21	100	81
7/27/2007	30.6	22.9	0	100	79
7/28/2007	33.1	21.8	0	100	69
7/29/2007	34	23.9	0	100	69
7/30/2007	34.1	24.4	0	100	67
7/31/2007	34.6	24	0	100	60
8/1/2007	34.6	23.5	0	100	63
8/2/2007	30.7	22.5	0.24	100	90
8/3/2007	34	22.8	0	100	68
8/4/2007	34.2	22.3	0.05	100	68
8/5/2007	34	23.3	0	100	69
8/6/2007	34.1	23.4	0	100	70
8/7/2007	34.6	23.5	0	100	62
8/8/2007	34.4	23.4	0	100	67
8/9/2007	34.9	21.1	0	100	63
8/10/2007	35.8	23.6	0	100	62
8/11/2007	37	23.6	0	100	53
8/12/2007	38.3	23.4	0	100	52
8/13/2007	37.6	23.3	0	100	48
8/14/2007	39.4	22.6	0	100	48
8/15/2007	37.3	24.2	0	100	52
8/16/2007	29.1	23	0.52	100	96
8/17/2007	33.8	24.3	0.37	100	79
8/18/2007	34.8	24.4	0.01	100	72
8/19/2007	34	23.1	0	100	69
8/20/2007	33.6	23.4	0	100	65
8/21/2007	34.5	22.4	0	100	67
8/22/2007	33.7	22.9	0.07	100	74
8/23/2007	34.6	23.9	0	100	68
8/24/2007	34.4	22.8	0	100	62

8/25/2007	34.9	21.8	0	100	60
8/26/2007	35.5	22.5	0	100	59
8/27/2007	34.7	21.9	0	100	65
8/28/2007	34	20	0.25	100	68
8/29/2007	33.3	22.7	0	100	67
8/30/2007	34.5	22.5	0	100	65
8/31/2007	33.2	22.3	0.13	100	66

APPENDIX C

SOURCES OF MATERIALS

SOURCES OF MATERIALS

Chapter II

[1] 11002 flat fan nozzle, TeeJet Spraying Systems Co.; Wheaton, IL 60189.

[2] Crop oil concentrate, Agri-Dex®, is a nonionic spray adjuvant consisting of a blend of heavy paraffin based petroleum oil, ployol fatty acid esters, and polyethoxylated derivatives. Helena Chemical Company, 6075 Poplar Avenue, Suite 500, Memphis, TN 38119.

Chapter III

[3] 11002 flat fan nozzle, TeeJet Spraying Systems Co.; Wheaton, IL 60189.

[4] Crop oil concentrate, Agri-Dex®, is a nonionic spray adjuvant consisting of a blend of heavy paraffin based petroleum oil, ployol fatty acid esters, and polyethoxylated derivatives. Helena Chemical Company, 6075 Poplar Avenue, Suite 500, Memphis, TN 38119.

APPENDIX D

CONVERSION OF DATA IN TABLES AND FIGURES FROM THE METRIC TO ENGLISH SYSTEM

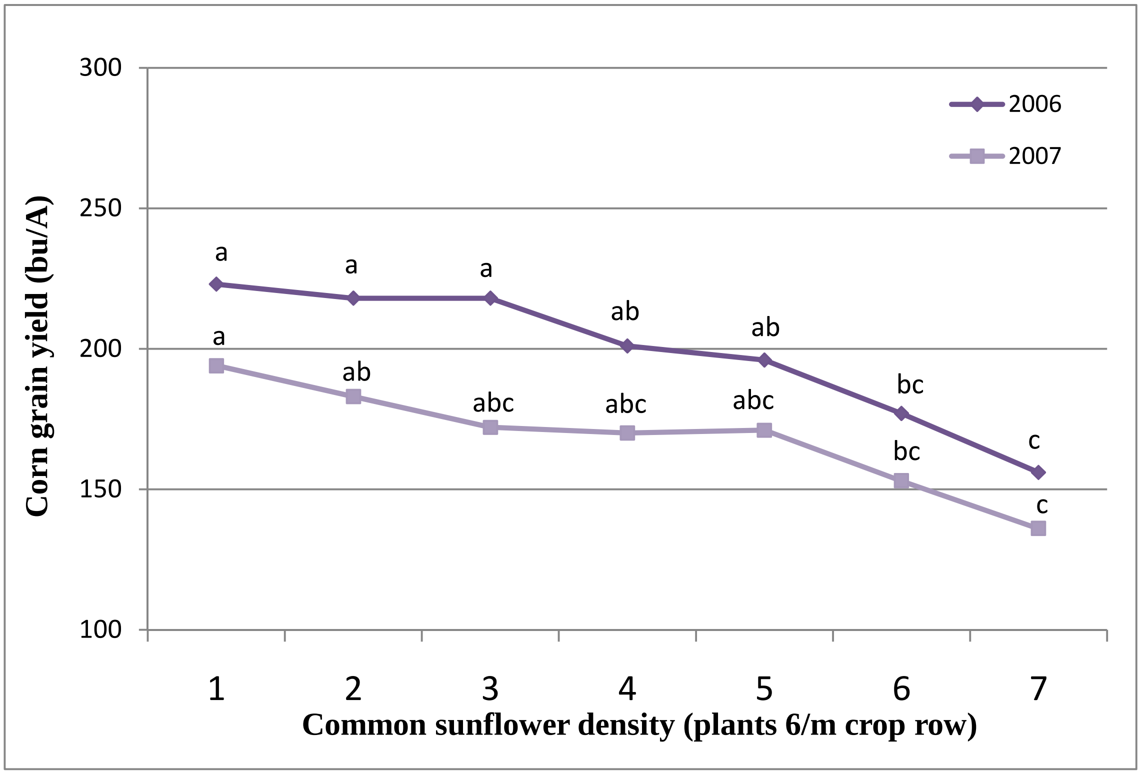

Figure D-1. Corn grain yield as affected by common sunflower density in 2006 and 2007. Means within each year were separated using Tukey's Protected HSD test ($P \leq 0.05$).

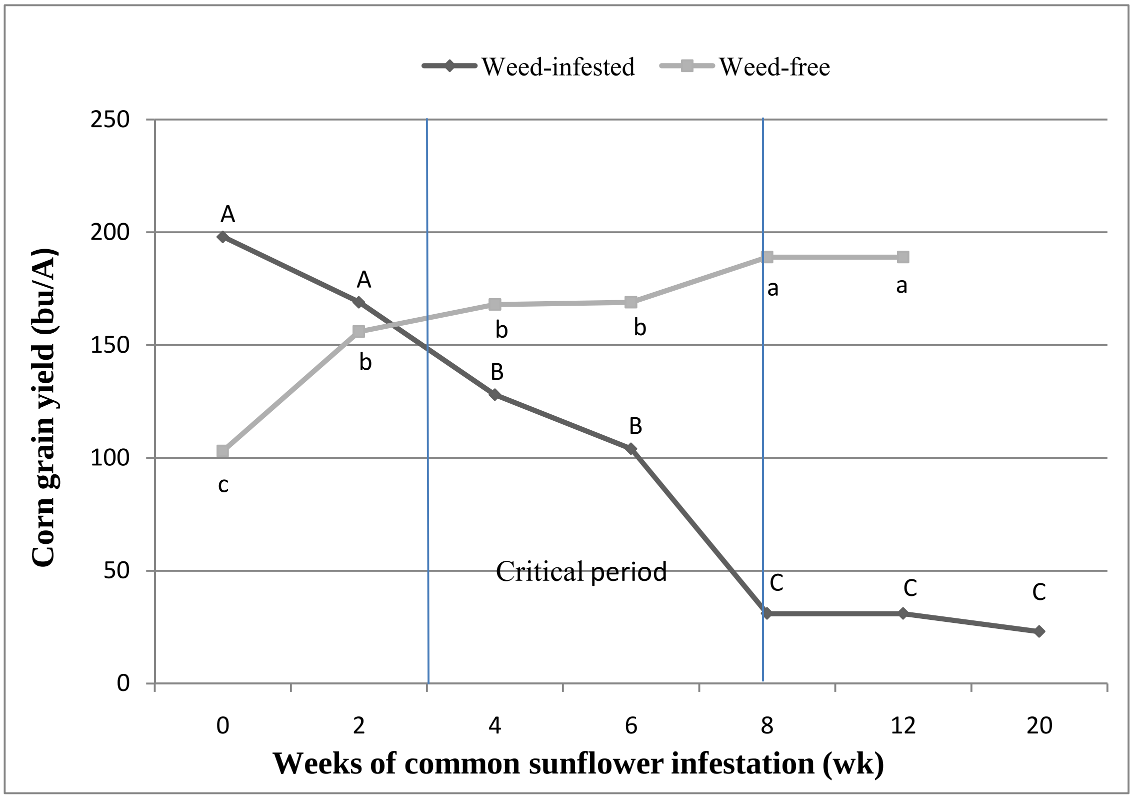

Figure D-2. Corn grain yields as affected by increasing durations of common sunflower infestation after planting, maintained either weed-infested or weed-free in 2006. The weed-infested (lower case) and weed-free (upper case) treatments with the same letters for each week of infestation are not significnatly different according to the Tukeys Protected HSD test ($P \leq 0.05$). The critical period is outined by the lines at 3 and 8 week of infestation.

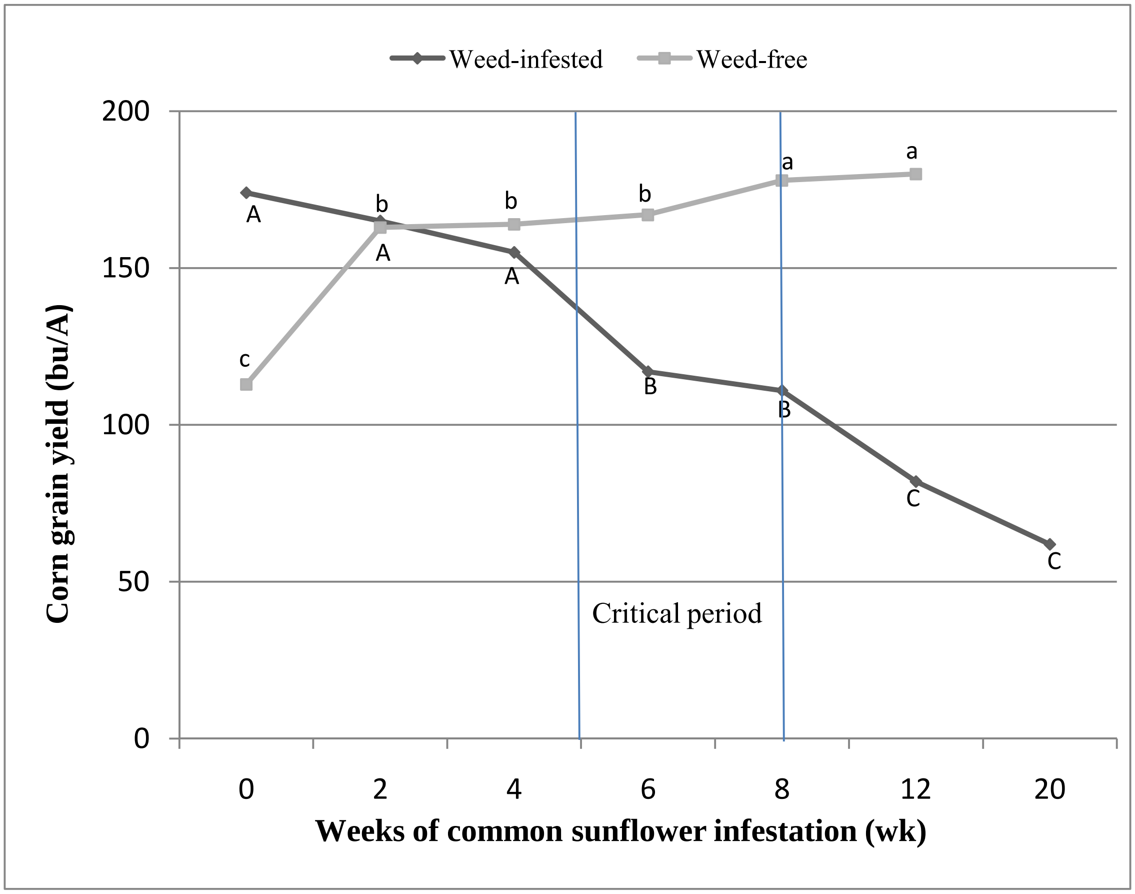

Figure D-3. Corn grain yields as affected by increasing durations of common sunflower infestation after planting, maintained either weed-infested or weed-free in 2007. The weed-infested (lower case) and weed-free (upper case) treatments with the same letters for each week of infestation are not significnatly different according to the Tukeys Protected HSD test ($P \leq 0.05$). The critical period is outined by the lines at 5 and 8 week of infestation.

Table D-1. Common sunflower control and corn grain yield from different weed-control programs in 2006.

			Common sunflower		
Herbicide[a]	Rate [b]	Timing[c]	14 DAT[c]	42 DAT	Grain yield
	lb ai/A		—— % control ——		—bu/A—
Non-treated			0 e[d]	0 e	49 c
Atrazine broadcast	1.0	PRE	86 ab	87 ab	148 a
fb glyphosate	0.95	POST	95 a	97 a	159 a
fb halosulfuron	0.032	POST	95 a	97 a	130 ab
fb halosulfuron + nicosulfuron	0.032 + 0.032	POST	95 a	99 a	141 ab
Atrazine banded[e]	1.0	PRE	41 d	45 d	102 b
fb glyphosate	1.06	POST	95 a	92 a	140 ab
Halosulfuron	0.032	POST	95 a	92 a	130 ab
+ nicosulfuron	0.032 + 0.032	POST	95 a	94 a	115 ab
Glyphosate	0.95	POST	95 a	95 a	128 ab

Table D-1. Continued.

Herbicide[a]	Rate[b]	Timing[c]	Common sunflower 14 DAT[c]	Common sunflower 42 DAT	Grain yield
	lb ai/A		% control		bu/A
Nicosulfuron	0.032	POST	53 c	57 c	96 b
Atrazine + *S*-metolachor	1.66	PRE	76 b	76 b	118 ab

[a] "+", tankmix; fb, followed by.

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

[c] Abbreviations: PRE, preemergence; POST, postemergence (V4 to V5 corn); DAT, days after late postemergence treatment.

[d] Means within columns for each DAT followed by different letters are significantly different at $p \leq 0.05$.

[e] Banded atrazine was applied in a 30-cm band and not over the entire treatable surface.

Table D-2. Common sunflower control and corn grain yield from different weed-control programs in 2007.

Herbicide[a]	Rate[b]	Timing[c]	Common sunflower 14 DAT	Common sunflower 42 DAT	Grain yield
	lb ai/A		— % control —		—bu/A—
Non-treated			0 f[d]	0 d	53 e
Atrazine broadcast	1.0	PRE	88 bc	88 a	149 abc
fb glyphosate	0.95	POST	100 a	99 a	162 a
fb halosulfuron	0.032	POST	100 a	99 a	156 ab
fb halosulfuron+ nicosulfuron	0.032 + 0.032	POST	100 a	99 a	149 abc
Atrazine banded[e]	1.0	PRE	73 d	70 b	125 bcd
fb glyphosate	0.95	POST	98 ab	98 a	157 ab
Halosulfuron	0.032	POST	87 c	96 a	131 a-d
+ nicosulfuron	0.032 + 0.032	POST	88 bc	99 a	141 abc
Glyphosate	0.95	POST	98 ab	96 a	137 abc

Table D-2. Continued.

			Common sunflower		
Herbicide[a]	Rate[b]	Timing[c]	14 DAT[c]	42 DAT	Grain yield
	lb ai/A		% control		bu/A
Nicosulfuron	0.032	POST	53 c	57 c	100 b
Atrazine + *S*-metolachor	1.66	PRE	76 b	76 b	120 ab

[a] "+", tankmix; fb, followed by.

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

[c] Abbreviations: PRE, preemergence; POST, postemergence (V4 to V5 corn); DAT, days after late postemergence treatment.

[d] Means within columns for each DAT followed by different letters are significantly different at p≤0.05.

[e] Banded atrazine was applied in a 30-cm band and not over the entire treatable surface.

Table D-3. Economic losses associated with common sunflower densities in commercial corn production, College Station, TX, 2006-2007.[a]

	Net corn price ($/A)[b]				
	2.00	3.00	4.00	5.00	6.00
Density[c]	Losses in dollars/A ($/A)[d]				
0	-	-	-	-	-
1	9	14	19	23	28
2	19	28	37	47	56
3	28	42	56	70	84
4	37	56	75	93	112
5	47	70	93	116	140
6	56	84	112	140	168
7	65	98	130	163	196
8	75	112	149	186	224

[a] Corn yield analysis: Y = 13,130.4 - 1,570.9 YR -293.0 SD; adjusted R^2= 0.38; F-statistic for the regression of 148 ($P<0.0001$). The t-statistics are significant at a P level of ≤ 0.05.
No significant difference across years was detected in the statistical analysis so all data are pooled for analysis.
[b] The net corn price ranges from $ 0.08 to $0.24/kg that equated to $2.00 and $6.00/bu. No herbicide applications are considered.
[c] Number of common sunflower plants/6 m of crop row.
[d] Dollar losses/ha for corn due to common sunflower densities at different net corn prices.

Table D-4. Gross economic returns associated with different corn density levels and losses resulting from common sunflower plants in commercial corn production, College Station, TX, 2006-2007[a].

Treatments[c]		Corn density[b] 11	15	19	23	27
	Net corn prices ($)	2006				
Without weeds		Dollar return/A				
	$ 2.00	245	250	265	266	229
	$ 3.00	378	389	415	420	369
	$ 4.00	511	527	564	574	508
	$ 5.00	643	666	714	728	647
	$ 6.00	776	805	864	882	786
With weeds[d]						
	$ 2.00	211	226	251	262	236
	$ 3.00	327	353	394	415	378
	$ 4.00	443	480	537	567	521
	$ 5.00	559	606	680	719	663
	$ 6.00	647	733	823	871	805
		2007 Location A				
Without weeds						
	$ 2.00	188	192	208	209	172
	$ 3.00	292	303	329	334	282
	$ 4.00	396	413	450	459	393
	$ 5.00	500	523	571	585	503
	$ 6.00	604	633	692	710	614

Table D-4. Continued.

Treatments[c]		Corn density[b]				
		11	15	19	23	27
	Net corn prices ($)	2006				
With weeds		Dollar return/A				
	$ 2.00	154	169	194	205	179
	$ 3.00	241	267	308	329	292
	$ 4.00	328	365	422	452	406
	$ 5.00	415	463	537	575	520
	$ 6.00	502	561	651	699	633
		2007 Location **B**				
Without Weeds						
	$ 2.00	191	196	211	212	175
	$ 3.00	296	307	333	339	287
	$ 4.00	402	419	456	465	399
	$ 5.00	508	530	578	592	511
	$ 6.00	613	642	701	719	623
With weeds						
	$ 2.00	157	172	197	208	182
	$ 3.00	245	271	313	333	297
	$ 4.00	334	371	428	458	412
	$ 5.00	423	471	544	583	527
	$ 6.00	511	570	660	708	642

Table D-4. Continued.

Treatments[c]	Corn density[b] 11	15	19	23	27
Net corn prices ($)					
	Cost of weed[e]				
$ 2.00	34	24	14	4	(6)[f]
$ 3.00	51	36	21	5	(10)
$ 4.00	68	48	27	7	(13)
$ 5.00	85	60	34	9	(16)
$ 6.00	102	72	41	11	(19)

[a] Corn yield analysis: Y = 16,079.7 -1,804.2 YRPLOT2007A -1,709.4 YRPLOT2007B -635.1 POP + 16.4 POP^2-0.1 POP^3 -1,989.7 WEED + 31.8 POPWEED; adjusted R^2= 0.70; F-statistic for the regression of 40.6. The t-statistics are significant at a probability level of ≤0.05.
[b] Corn density measured in 1000 plants/A.
[c] (Without weeds)- no common sunflowers present; (With weeds)-common sunflowers present; (Cost of weed)- losses due to common sunflower interference
[d] Common sunflower density is 4 plants/6 m of crop row.
[e] Losses in dollars/A.
[f] ( ) represents net increase.

Table D-5. Gross economic returns associated with different weeks of competition of common sunflower plants in commercial corn production, College Station, TX, 2006.[a]

Weeks of competition (wk)[c]	Net corn price ($/bu)[b] $ 2.00	$ 3.00	$ 4.00	$ 5.00	$ 6.00
	Dollar return				
0	411	616	822	1,027	1,233
1	365	547	729	911	1,094
2	321	482	642	803	963
3	281	421	561	701	842
4	243	365	486	608	729
5	208	313	417	521	625
6	177	265	354	442	531
7	148	222	296	371	445
8	123	184	245	306	368
9	100	150	200	250	300
10	80	120	160	200	241
11	63	95	127	159	190
12	50	74	99	124	149
13	39	58	78	97	117
14	31	47	62	78	93
15	26	39	52	65	78
16	24	36	49	61	73
17	25	38	51	63	76
18	29	44	59	73	88
19	36	55	73	91	109
20	46	70	93	116	139

[a] Corn yield analysis: $Y = 12{,}924.1 - 1{,}507.2WK + 46.7\ WK^2 - 1{,}523.9\ YR + 830.0\ WKYR - 31.8\ WK^2YR$; adjusted $R^2 = 0.93$; F-statistic was 142. The t-statistics are significant at a probability level of ≤ 0.05.

[b] The net corn price ranges from $0.08 to $0.24/kg equating to $2.00 and $6.00/bu.

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

Table D-6. Gross economic returns associated with different weeks of competition of common sunflower plants in commercial corn production, College Station, TX, 2007.[a]

	Net corn price ($/bu)[b]				
Weeks of competition (wk)[c]	$ 2.00	$ 3.00	$ 4.00	$ 5.00	$ 6.00
	Dollar return				
0	362	544	725	906	1,087
1	341	512	683	854	1,024
2	321	482	643	803	964
3	302	453	604	755	906
4	284	426	568	710	852
5	267	400	533	667	800
6	250	376	501	626	751
7	235	352	470	587	705
8	221	331	441	551	662
9	207	311	414	518	621
10	195	292	389	486	584
11	183	275	366	458	549
12	172	259	345	431	517
13	163	244	325	407	488
14	154	231	308	385	462
15	146	219	292	365	439
16	139	209	279	348	418
17	133	200	267	334	400
18	129	193	257	321	386
19	125	187	249	311	374
20	122	182	243	304	365

[a] Corn yield analysis: $Y = 12{,}924.1 - 1{,}507.2WK + 46.7\ WK^2 - 1{,}523.9\ YR + 830.1\ WKYR - 31.8\ WK^2YR$; adjusted $R^2 = 0.93$; F-statistic was 142. (significant at the 2.58 E-28 level). The t-statistics are significant at a probability level of ≤ 0.05.

[b] The net corn price ranges from \$0.08 to \$0.24/kg equating to \$2.00 and \$6.00/bu.

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

Table D-7. Net returns of various herbicide applications for the control of common sunflower, 2006 and 2007.

Herbicide[a]	Rate[b]	Timing[c]	—Net returns[f] —	
			2006	2007
	1b ai/A		— Dollars/A ($/A) —	
Non-treated			242 d[d]	260 d
Atrazine broadcast	1.0	PRE	720 ab	723 ab
fb glyphosate	0.95	POST	761 a	774 a
fb halosulfuron	0.036	POST	612 abc	742 a
fb halosulfuron + nicosulfuron	0.032 + 0.032	POST	646 abc	682 ab
Atrazine banded[e]	1.0	PRE	498 c	608 abc
fb glyphosate	0.95	POST	671 abc	751 a
Halosulfuron	0.032	POST	624 abc	628 ab
+ nicosulfuron	0.032 + 0.032	POST	524 bc	654 ab
Glyphosate	0.95	POST	616 abc	659 ab
Nicosulfuron	0.032	POST	461 cd	461 c
Atrazine + *S*-metolachor	1.66	PRE	561 abc	572 bc

[a] "+", tank mix; fb, followed by.
[b] Rates of herbicides are based upon labeled rates for specific soil characteristics.
[c] Abbreviations: PRE, preemergence; POST, postemergence (V4 to V5 corn); DAT, days after late postemergence treatment.
[d] Means within columns for each DAT followed by different letters are significantly different at $P \leq 0.05$.
[e] Banded atrazine was applied in a 30-cm band and not the entire treatable surface.

VITA

Nyland Ray Falkenberg was born in Uvalde, Texas and attended high school in Knippa, Texas and graduated in May 1996. He then attended Southwest Texas Junior College while starting his own wildlife management business. In 1998 he attended Texas A&M University-Kingsville where he graduated with a Bachelor of Science degree in range and wildlife management in December 2000. After graduating he continued his own business and worked part-time for Texas AgriLife Research. In February 2002 he began his master's degree program at Texas A&M University in College Station, Texas where he specialized in cotton physiology. Research focused on the remote sensing of site-specific management of biotic and abiotic stresses in cotton. In May 2004, he graduated with a Master of Science degree in agronomy and then moved to Uvalde, Texas to begin working at the Texas AgriLife Research Station in crop physiology. In April 2005 he started at Texas A&M University to pursue a Doctor of Philosophy degree in agronomy specializing in weed management in various crops. In May of 2009, Nyland was awarded a Doctor of Philosophy degree in agronomy.

Nyland is a member of several organizations including Southern Weed Science Society, Weed Science Society of America, American Society of Agronomy, and Texas Plant Protection Association. Nyland has authored 3 refereed journal articles, 12+ published abstracts, co-authored 2 published abstracts, and given 3 invited presentations. Nyland can be reached at Texas A&M University, Department of Soil and Crop Sciences, 370 Olsen Blvd., College Station, TX 77843-2474.