WEED CONTROL IN HERBICIDE-TOLERANT SUNFLOWER

by

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ABSTRACT

Several weed species infest sunflower fields, but herbicidal options for broadleaf weed control are limited. In recent years, imazamox and tribenuron herbicides have been registered for POST use in imidazolinone-tolerant and tribenuron-tolerant sunflowers, respectively. Objectives of this study were to 1) investigate the effects of soil nitrogen level on Palmer amaranth control with imazamox in imidazolinone-tolerant sunflower and 2) evaluate crop response and weed control efficacy of single and sequential applications of tribenuron at two rates and the effectiveness of preemergence herbicides followed by postemergence tribenuron in tribenuron-tolerant sunflower. Greenhouse experiments were conducted in Manhattan, KS and field experiments were conducted near Hays, KS in 2007 and 2008. For the first objective, treatments consisted of a factorial arrangement of three soil nitrogen levels (28, 56, and 84 kg/ha) and two imazamox rates (26 and 35 g ai/ha) in a RCBD. Palmer amaranth growth rate increased with increasing soil nitrogen level. In all experiments, plants grown at the highest soil nitrogen level exceeded the maximum recommended plant height (7.6 cm) by >35% at the time of imazamox application. Generally, imazamox rates did not differ in control effectiveness at the 56 kg/ha soil nitrogen level, but the higher 35 g/ha rate was superior to the lower rate at the 84 kg/ha soil nitrogen level because of greater weed size. For the second objective, tribenuron was applied singly at 9 and 18 g/ha, sequentially in all combinations of those rates, and singly at those rates following PRE herbicide treatments. In general, tribenuron at 18 g/ha applied with methylated seed oil adjuvant before weeds exceeded 10 cm in height provided excellent control of most species with insignificant injury to the crop. The need for supplemental PRE herbicides for weed control in tribenuron-tolerant sunflower depends on weed species present and their size at the time of tribenuron application.

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Literature Review

Sunflower (*Helianthus annuus* L.) is an important domesticated crop in many dryland farming systems, with yields largely dependent on climatic conditions (Chapman et al. 1993). In rainfed production systems such as in the central Great Plains of the United States including western Kansas, sunflower often is grown in rotation with winter wheat, corn, or grain sorghum with a fallow period usually following sunflower in the rotation. Moisture conserving crop production techniques such as no-till (NT) and minimum till allow more flexibility in crop choice and have increased dryland cropping intensity and the viability of summer crops such as sunflower in particular. Indeed, sunflower is well-adapted to the long growing season and warm summer temperatures found in this region (Johnston et al. 2002). Furthermore, sunflower has potential to thrive better under drought condition as compared to other row crops grown in the region. This is because sunflower extracts more water from deeper soil depths as compared to sorghum, corn, pearl millet, and soybean (Hattendorf et al. 1988). However, crop choice depends on several factors such as environmental (climate, soil fertility, soil moisture status), input supply and cost, risk from biotic agents such as weeds, insects, and diseases, and available pest management options.

Water is the principal limiting resource for dryland crop production in western Kansas. Sunflower cannot be defined as highly tolerant to drought, but its ability to explore the soil profile helps it to survive under drought conditions better than many other crops grown in the region, if there is water available deep in the soil profile. Sunflower fits well into conventional, reduced and NT systems. The introduction of NT in the central Great Plains has been presented as a way to increase soil water accumulation. A number of authors, including Aase and Schaefer (1996), McGee et al. (1997), Peterson et al. (1996), and Tanaka and Anderson (1997) have reported greater soil water storage under NT and minimum tillage than under conventional tillage. In the semi-arid region of western Kansas, crops and weeds compete for plant growth resources including light, nutrients, and especially water (Zimdahl 1999).

Several summer annual weed species including highly competitive *Amaranthus* spp. infest sunflower fields in western Kansas. Field surveys have indicated that Palmer amaranth (*Amaranthus palmeri* L.) is a major weed of sunflower in Kansas. Nearly two-thirds of the fields surveyed were infested with Palmer amaranth (Berglund 2007). Weise (1968) reported that Palmer amaranth roots expand rapidly, which serves as a mechanism to compete for soil water (Davis et al. 1967). Thus, dryland sunflower production can be a challenge in western Kansas in the presence of highly competitive weeds.

Weeds have always been a problem in sunflower production. Sunflower is usually planted in wide rows and at lower densities than many other crops. Sunflower grows slowly the first two to three weeks after emergence. Consequently, weeds that emerge during this time have a good opportunity to establish in the wide inter-row spaces. The most common and troublesome weeds in sunflower fields in the central Great Plains include pigweed species, kochia (*Kochia scoparia* L. Schrad.), and Russian thistle (*Salsola iberica* Sennen and Pau) (Lamey et al. 1999). Among the pigweeds commonly present in this region, Palmer amaranth grows most rapidly, attains the tallest height, and accumulates the most biomass (Horak and Loughin 2000). It has become the most common and troublesome pigweed species in many areas of Kansas (Stahlman and Wicks 2000).

Growers have traditionally relied on preemergence herbicides for weed control in sunflowers. However, soil-active preemergence herbicides are expensive and require timely rainfall or irrigation for activation. Also, some are marginally effective because of the narrow spectrum of weeds controlled (Miller and Alford 2000). In recent years, development of herbicide-tolerant sunflower has opened up a new arena in weed management in sunflower. Tolerance to imidazolinone and tribenuron herbicides has been incorporated into domesticated sunflower through conventional breeding methods (Al-Khatib and Miller 2000; Miller and Al-Khatib 2002, 2004). Shaner (2000) argues that simplicity of the herbicide systems and effectiveness on a broad-spectrum of weeds makes herbicide-resistant crops more attractive options than conventional crops. This holds true especially for crops such as sunflower, which have limited broadleaf herbicide options (Howatt and Endres 2006). Currently, imazamox and tribenuron are labeled for use in herbicide-tolerant sunflower hybrids specifically limited to each herbicde.

With increasing cost of crop production and the increase in environmental pressure for reduced herbicide inputs, greater emphasis has been placed on applying reduced rates of herbicides in recent years. Apart from herbicides, nitrogen is another major input in agriculture. Studies have reported independent and combined effects of reduced rates of nitrogen and herbicides on crop-weed competition and weed control efficacy (Kim et al 2006; Salonen 1992; Wright and Wilson 1992). Chao et al. (1994) and Dickson et al. (1990) argue that nitrogen availability in the soil can influence herbicide performance. The effect of increased nitrogen often increases weed susceptibility to herbicide (Lutman et al. 2006; and Kim et al. 2006). Producers often reduce the rate of one or both of these major inputs to economize their production cost. However, such crop production practices may lead to weed control failure resulting in huge economic loss. Kim et al. (2006) highlighted the necessity of understanding the interaction between herbicide and soil nitrogen to avoid such failure.

Therefore, field and greenhouse studies were conducted to:

1. Investigate the interactive effects between soil nitrogen level and imazamox rate on Palmer amaranth control and crop yield in imidazolinone-tolerant sunflower.
2. Evaluate crop response and weed control and assess the need of supplemental preemergence herbicides in tribenuron-tolerant sunflower.

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CHAPTER I

INTERACTION BETWEEN SOIL NITROGEN AND IMAZAMOX ON PALMER AMARANTH CONTROL IN IMIDAZOLINONE-TOLERANT SUNFLOWER

ABSTRACT

Greenhouse and field experiments were conducted to investigate the interaction between soil N level and imazamox rate on Palmer amaranth control and crop seed yield in imidazolinone-tolerant sunflower. Treatments included factorial arrangements of three soil N levels (28, 56, and 84 kg/ha) and two imazamox rates (26 and 35 g ai/ha). Field experiments in 2007 and 2008 included hand weeded and untreated controls. Palmer amaranth height at the time of imazamox application was taller with increasing soil N level in all experiments. Except in the 2007 field experiments, the two imazamox rates did not differ in percent Palmer amaranth biomass reduction at the 56 kg/ha soil N level. In the 2007 field study, percent biomass reduction was similar at the 84 kg/ha soil N level between the two rates of imazamox. Timely early-season rainfall and low weed density in 2007 likely eliminated the effect of weed size on imazamox efficacy. Slight (<5%) transitory chlorosis occurred with 35 g/ha of imazamox at 84 kg/ha soil N level. Sunflower seed yield did not differ among the treatments in either year. These results indicate the lower-than-labeled rate tested (26 g/ha) can be as effective as the recommended use rate of imazamox when soil N level is not limited and size of Palmer amaranth plants does not exceed label recommendation.

Nomenclature: Imazamox; Palmer amaranth, *Amaranthus palmeri* L.; sunflower, *Helianthus annuus* L. 'Triumph 660CL'

Key words: herbicide injury, imidazolinone-tolerant sunflower, soil N, herbicide interaction, sub-optimal herbicide rate, weed biomass.

Abbreviations: N, nitrogen; WAT, weeks after treatment.

Introduction

Several species of *Amaranthus* occur throughout the Great Plains of the United States (Horak et al. 1994) and are among the most troublesome weed species in agronomic production systems. During the past decade Palmer amaranth (*Amaranthus palmeri* S. Wats.) has spread throughout the southern Great Plains and into the central Great Plains and across Kansas to become the most common and troublesome pigweed species in many areas, displacing most other pigweed species (Stahlman and Wicks 2000). Palmer amaranth has been reported to reduce crop yields in soybean (Bensch et al. 2003; Klingaman and Oliver 1994), corn (Massinga et al. 2001), and cotton (Morgan et al. 2001; Rowland et al. 1999). Palmer amaranth competitiveness is a result of its capacity for rapid growth (Horak and Loughin 2000) and its ability to spread rapidly (Keeley et al. 1987). The growth rate and competitive ability of this species exceeds that of most other *Amaranthus* species. Palmer amaranth had greater growth at higher temperatures than redroot pigweed (*A. retroflexus* L.) or common waterhemp (*A. rudis* Sauer), in part, because of its extensive root growth and greater thermostability of its photosynthetic apparatus (Guo and Al-Khatib 2003). Palmer amaranth produced the highest plant volume, dry weight, and leaf area of all *Amaranthus* species studied and had the largest rate of height increase (Horak and Loughin 2000; Sellers et al. 2003). In addition to its competitive attributes, the success of Palmer amaranth as a weed in summer annual row crops is aggravated by its high fecundity and long seed dormancy compared to other annual weed species (Keeley et al.1987).

The decision to implement weed control is influenced by the ability of the weed to reduce crop yield, on how much seed will be added to the seed bank if not controlled, and on the costs of control (fuel, machinery, herbicide costs, application costs, etc.). Pendimethalin has been the herbicide most commonly used for weed control in conventional sunflower, but it is inconsistent against pigweed species including Palmer amaranth. With the commercial registration in 2003 of imidazolinone-tolerant sunflowers in the United States as Clearfield® sunflower (Tan et al. 2005), POST broadleaf herbicide options became possible in sunflower. Currently, imazamox is the only herbicide labeled for POST use in Clearfield® sunflower (Anonymous 2008). Tribenuron is a cheaper POST weed control option for use in tribenuron-tolerant sunflower, but tribenuron controls only broadleaf weeds. Thus, despite its higher cost, some growers are using POST imazamox in Clearfield® sunflower because of its effectiveness on both grass and broadleaf weed species that have not developed resistance to acetolactate synthase (ALS)-inhibiting herbicides (Blackshaw 1998; Nelson and Renner 1998).

Nitrogen is an essential macronutrient and a major input for producing crops. Its availability for plant uptake can influence both crop-weed competition (Carlson and Hill 1986) and herbicide performance (Chao et al. 1994; Dickson et al. 1990). Some researchers concluded that weeds benefit as much or more from fertile soils as crops, however, effects are specific to the crop and weed species present (Anderson et al. 1998; Bosnic and Swanton 1997; Carlson and Hill 1986; Kirkland and Beckie 1998; Tollenaar et al. 1994). Leaf area of most species increases with increasing soil N availability (Radin 1982), which can result in greater herbicide interception by plants.

Changes in soil N not only affect plant growth and development, but also influence physiological and biochemical processes such as uptake, translocation, and metabolism of herbicides (Mithila et al. 2008). Dickson et al. (1990) reported that oats (*Avena sativa* L.) were more tolerant to fluazifop and glyphosate when grown under a low N than a high N environment. A growth chamber study indicated that high soil N level improved the efficacy of some herbicides on redroot pigweed and green foxtail (Cathcart et al. 2004). Therefore, to achieve adequate weed control in N-deficient environments, herbicide rate or frequency of application may need to be increased. Conversely, a lower than labeled rate of herbicide may provide satisfactory weed control in a N-rich environment. Sunflower roots generally are able to penetrate and extract nutrients and soil water from deeper in the soil profile than most other row crops (Stone et al. 2001); however, sunflowers often respond to fertilization on many High Plains soils (HPSPH 2005).

Herbicides and fertilizer are major input costs in Great Plain's cropping systems (Derksen et al. 2002; Grant et al. 2002; Schlegel et al. 2005). Because of their high costs growers often limit either or both inputs in sunflower fields; some use lower than labeled herbicide rates. This could have unintended negative effects on weed control. Recent studies suggest a cautious approach when combining reduced inputs because of greater risk of weed control failure (Kim et al. 2006a, 2006b; Richards 1993). To minimize such risks, it is essential to understand the interactions between herbicide rate and soil N level when crop plants and weeds compete for limited resources and to quantify interactions in terms of crop yield or weed seed production (Kim et al. 2006b).

There is need to investigate the effects of sub-optimal herbicide and N rates on control of Palmer amaranth because of its robust growth habit and increasing presence in Kansas cropland and because the high cost of herbicide and fertilizer inputs tempt growers to cut rates of one or both. The hypothesis is that the susceptibility of Palmer amaranth to imazamox increases with increasing soil N levels thereby indirectly increasing the performance of a lower rate of imazamox. The objective of the experiment was to investigate the relationship between imazamox rates and soil N levels on Palmer amaranth control. The results from this study will assist sunflower growers in making informed herbicide and N fertility decisions.

Materials and Methods

Greenhouse experiment. A repeated greenhouse experiment was conducted in the Kansas State University Weed Science greenhouse in February and April 2008. Palmer amaranth plants were grown in 20-cm by 10-cm by 10-cm plastic containers filled with a 1:4 (v/v) mixture of sand and soil from a field at Kansas State University North Farm, Manhattan, KS. The field had not received N fertilizer for more than 15 years. The final sand:soil mixture had pH value of 7.5, 2.8 ppm nitrate N and 2.7% organic matter. The experiment consisted of three levels of soil N (28, 56, and 84 kg N/ha) and two rates of imazamox (26 and 35 g/ha) plus an untreated control. Treatments were arranged in a completely randomized design and were replicated five times. Urea fertilizer (46:0:0 NPK) required to achieve 28, 56, and 84 kg N/ha was mixed with the soil mixture before filling pots. Palmer amaranth seeds were sown in two rows 5 cm apart at the rate of 50 seeds/row. Water was added through subsurface irrigation to ensure Palmer amaranth seed germination. Within a week after emergence, four equally spaced Palmer amaranth seedlings per row were selected and the rest were removed using a forceps. Growing conditions in the greenhouse were 30 ± 3 and 21 ± 3 C day and night temperatures, respectively, with a 16:8–h day/night period, supplemented with 120 mmol/m^{2}s illumination provided with sodium vapors lamps. Palmer amaranth plants were treated with 26 or 35 g/ha of imazamox when all plants within each soil N level exceeded 6 cm in height. Imazamox was applied with a moving single-nozzle bench-type sprayer[1] equipped with a flat-fan nozzle tip[2] (80015LP) delivering 168 L/ha at 222 kPa in a single pass at 4.8 km/h over the Palmer amaranth foliage. Both imazamox treatments included ammonium sulfate (AMS) at 5% w/v and nonionic surfactant (NIS) at 0.25%

v/v. Plant response to herbicide application was determined by harvesting aboveground biomass 2 weeks after treatment (WAT), dried at 75 C for 72 h and weighed. Percent biomass reduction for the two imazamox rates at each soil N level was determined by converting the dry biomass to a percent reduction based on untreated controls within soil N level.

Field Experiment. Field experiments were conducted in 2007 and 2008 at the Kansas State University Agricultural Research Center,Hays, KS on a Crete silty clay loam soil (fine, montmorillonitic, mesic Pachic Argriustolls). The top 30 cm of soil had pH 6.4 and 6.9, 2.0 and 1.7% organic matter, and 1.5 and 4.3 ppm of nitrate N in 2007 and 2008, respectively. Experimental design was a randomized complete block with factorial arrangements of two imazamox rates (26 and 35 g/ha) plus weedy and weed-free controls, and three N levels. Each treatment was replicated four times.

Prior to planting, N content was determined to a depth of 1.2 m in 30 cm increments based on the results of the nutrient analysis of a composite sample of several soil cores taken from the experimental area. Soil N fertility was supplemented with nitrogen fertilizer in amounts needed to achieve total nitrate N levels of 28, 56 and 84 kg/ha in the top 30 cm of soil before planting. In 2007, 28% UAN was applied at the designed rates with a tractor-mounted sprayer[1] on May 29. In 2008, urea was broadcast on individual plots by hand on June 3. The fertilizer was incorporated to a depth of 5 cm within 2 days after application. Plots were overseeded with Palmer amaranth seeds at 150 seeds/m^2 using an air-delivery granular herbicide applicator. 'Triumph 660CL' variety of Clearfield® sunflower was planted at a rate of 49,000 seeds/ha with a planter[3] at a depth of 3 to 5 cm on June 7, 2007 and June 5, 2008. Plots were 3 by 15 m and encompassed four sunflower rows spaced 0.76-m apart. Weeds other than Palmer amaranth were removed by hand in the third week after planting.

Imazamox was applied 35 days after planting (DAP) in 2007 and 38 DAP in 2008. Height of 10 Palmer amaranth plants per plot was measured 1 or 2 days before applying herbicide treatments. Imazamox at 26 and 35 g/ha was applied in water with non-ionic surfactant using a CO_2-pressurized backpack sprayer and hand-held boom equipped with six wide-angle flat spray tips[4] spaced 45 cm apart delivering 122 L/ha at 221 kPa and 4.8 km/h. The 26 g/ha rate of imazamox was the suboptimal rate and the 35 g/ha rate is the recommended rate for use in sunflower (Anonymous 2006). Air temperature at the time of herbicide application was 24 and 25 C with 65 and 30% relative humidity in 2007 and 2008, respectively. All weeds were removed from weed-free plots within 3 days before or after imazamox application.

Sunflower injury was visually rated 7 days after treatment (DAT) of imazamox on a scale of 0 (no injury) to 100 (complete injury). Palmer amaranth plants were harvested for dry biomass 14 DAT. In 2007, five randomly selected plants from the inter-row space between the two center rows of sunflower were harvested from each plot. In 2008, because of the very high density of Palmer amaranth, plants were harvested from three random subplots per plot. A 23-cm diameter ring was placed randomly in the sunflower inter-row spaces and Palmer amaranth plants inside the ring were harvested. Harvested samples were oven-dried for 72 h at 75 C to determine dry biomass. Percent biomass reduction for the two imazamox rates at each soil N level was determined by converting the dry biomass to a percent reduction based on the untreated control at each soil N level. At the end of the season, the two center 9-m long sunflower rows were hand-harvested in 2007. In 2008, 13-m center two rows of sunflower were harvested with a plot combine. Hand-harvested heads in 2007 were dried and threshed with a plot combine. Seed yields were adjusted to 10% moisture content.

Statistical analysis. Data were subjected to factorial analysis of variance (ANOVA) using PROC GLM procedure in SAS[5]. Treatment means and interaction effects were separated using Fisher's Protected LSD at the 5% significance level. Orthogonal contrasts were used to compare soil N level and imazamox rate treatment combinations. Significant interactions occurred between years in the field experiment and between runs in the greenhouse experiment; therefore, data were analyzed separately for each year and run.

Results and Discussion

Greenhouse Experiment. Height of the Palmer amaranth plants at the time of imazamox application was taller with increasing soil N levels (Figure 1.1). The interaction between soil N levels and imazamox rates for percent Palmer amaranth biomass reduction was not significant (Table 1.1). However, both soil N level and imazamox rate main effects were significant.

In the first run, mean (± SE) plant heights were 8 ± 0.18, 10 ± 0.14, and 13 ± 0.15 cm for 28, 56, and 84 kg/ha soil N levels, respectively. For 26 g/ha imazamox, percent biomass reduction increased as the soil N level increased from 28 to 56 kg/ha ($P = 0.0010$) but not from 56 to 84 kg/ha ($P = 0.1096$) (Figure1.1a). For 35 g/ha, there was an increase in percent biomass reduction as soil N level increased from 28 to 56 kg/ha ($P < 0.0001$) but percent biomass decreased as soil N level increased from 56 to 84 kg/ha ($P = 0.0006$). Larger plants in the high soil N pots likely were affected by intraspecific competition for space and pot size limited root growth as well. Consequently, after attaining a certain size, plants in those pots started growing slowly resulting in a lower percent biomass reduction. There was a significant percent biomass reduction difference between 26 and 35 g/ha imazamox at 28 kg/ha ($P = 0.0099$) and 84 kg/ha ($P = 0.0916$) soil N levels but not at 56 kg/ha. The plants growing in the 56 kg/ha soil N level were slightly taller than the recommended maximum height of 7.6 cm. This indicated that the suboptimal rate of imazamox performed as well as the minimum recommended rate when both soil N content and the height of the plants were not limiting the efficacy of imazamox to a great extent.

In the second run, mean (± SE) plant heights were 7 ± 0.15, 9 ± 0.13, and 11 ± 0.22 cm for 28, 56, and 84 kg/ha soil N levels, respectively (Figure 1.1b). Percent biomass reduction in response to the 26 g/ha imazamox rate did not increase as soil N levels increased. For 35 g/ha imazamox, percent biomass reduction did not increase as soil N level increased from 28 to 56 ($P = 0.8672$) but did increase as the soil N level increased from 56 to 84 kg/ha ($P = 0.0003$). Percent biomass reduction in response to 28 kg/ha soil N ($P = 0.2483$) or 56 kg/ha soil N ($P = 0.3206$) did not differ between 26 and 35 g/ha imazamox rates. Palmer amaranth plants growing at 28 kg/ha soil N levels were within the recommended size on the label. As the soil N level increased from 56 to 84 kg/ha, there was a significant increase in percent biomass reduction as imazamox rate increased from 26 to 35 g/ha ($P = 0.0007$). These results revealed that the efficacy of suboptimal and recommended rates of imazamox was similar at low soil N level when Palmer amaranth plants were shorter than the recommended maximum height.

Field Experiment. Total precipitation received from May 15 to October 15 was 53 cm and 56 cm for 2007 and 2008, respectively (Figure 1.2). In 2007, 50% of the growing season precipitation occurred by the end of June, whereas in 2008, that proportion of precipitation did not occur until the fourth week of July. The early precipitation in 2007 provided nearly optimum growing conditions for sunflower and Palmer amaranth establishment. In 2008, precipitation deficits preceding and after planting of sunflower and Palmer amaranth generated moisture stress, especially on Palmer amaranth. The severity of moisture stress became more pronounced as dense populations of Palmer amaranth had established.

The pattern of precipitation during the early season growing period (10 days before through 40 days after planting) greatly influenced germination and establishment of Palmer amaranth. An early precipitation event (within 10 days before planting) in both years (Figure 1.3) initiated germination of Palmer amaranth, but varying patterns of subsequent rainfall events between years resulted in dissimilar growth behavior of Palmer amaranth. Cumulative precipitation for the period of 10 days prior to planting to 40 days after planting was substantially higher in 2007 with 220 mm than in 2008 with 100 mm. More than 700 mm of precipitation during the fourth week after planting in 2007 induced rapid Palmer amaranth growth. At this phase, which is often described as lag phase, plants often grow exponentially provided that the growing conditions are not limiting. In environments such as in western Kansas, soil resources are typically available for plant uptake only during periods following precipitation. N mineralization and nutrient movement to the root surface are high when soil moisture levels increase following precipitation events (Cui and Caldwell 1997). Thus, abundant precipitation during this phase of Palmer amaranth development in 2007 resulted in taller and less variable plants across N treatments (Figure 1.4a). In 2008, limited precipitation during the second and third week of planting caused Palmer amaranth to grow slowly at low N levels (Figure 1.4b). The dense population of Palmer amaranth (~100 plants/m^2) in 2008 further aggravated extent of moisture stress condition. Consequently, a highly significant variation in Palmer amaranth height among the N treatments was observed.

Palmer amaranth height at the time of imazamox application was taller with increasing soil N level in both years (Figure 1.4). There was no interaction between soil N level and imazamox rate in percent biomass reduction in either year (Table 1.1). However, main effects for soil N level and imazamox rate were significant.

In 2007, the mean (± SE) plant heights were 19 ± 0.31, 21 ± 0.27, and 23 ± 0.36 cm for 28, 56, and 84 kg/ha soil N levels, respectively. Percent biomass reduction in response to 26 g/ha imazamox rate increased as soil N levels increased from 28 to 56 ($P = 0.0077$) and from 56 to 84 kg/ha ($P < 0.0001$) (Figure 1.4a). Similarly, for 35 g /ha imazamox, percent biomass reduction increased as soil N levels increased from 28 to 56 kg/ha ($P = 0.0358$) and from 56 to 84 kg/ha ($P < 0.0001$). These results indicate that percent biomass reduction increased more when soil N level increased from 56 to 84 kg/ha than from 28 to 56 kg/ha. Percent biomass reduction differed between 26 and 35 g/ha rates of imazamox at soil N levels of 28 kg/ha ($P = 0.0056$) and 56 kg/ha ($P = 0.0266$) but not at the 84 kg/ha soil N level ($P = 0.1605$). However, difference in biomass reduction between the two rates of imazamox narrowed as soil N level increased to the extent that performance of the suboptimal dose of imazamox on percent biomass reduction was similar the recommended rate at the high soil N level.

In 2008, the mean (± SE) plant heights were 6 ± 0.19, 9 ± 0.22, and 10 ± 0.33 cm for the 28, 56, and 84 kg/ha soil N levels, respectively. For the 26 g/ha rate of imazamox, percent biomass reduction did not increase as soil N level increased from 28 to 56 kg/ha ($P = 0.0522$) or from 56 to 84 kg/ha ($P = 0.1096$) (Figure 1.4b). However, there was an increase in percent biomass reduction as the soil N level increased from 28 to 84 kg/ha. For the 35 g/ha rate of imazamox, percent biomass reduction did not increase as soil N levels increased from 28 to 56 ($P = 0.4971$), but increased as the N levels increased from 56 to 84 kg/ha ($P = 0.0082$). In contrast to 2007 results, these results indicated that better response may not always be observed with small incremental increases in soil N level. High Palmer amaranth density (~100 plants/ m^2) likely minimized the effect of N on herbicide efficacy. At the 5% probability level, percent biomass reduction was not different between 26 and 35 g/ha rates of imazamox at soil N levels of 28 kg/ha (P = 0.0762), 56 kg/ha (P = 0.6265), and 84 kg/ha (P = 0.0916). However, the two rates of imazamox differed at 28 kg/ha and 84 kg/ha soil N levels at the 10% probability level..

In 2007, sunflower plants growing in the 84 kg/ha soil N level and treated with 35 g/ha imazamox were slightly chlorotic (≤ 5%) at 7 DAT, but the chlorosis had disappeared at 14 DAT (data not shown). Abundant precipitation just before imazamox application (Figure 1.3) likely induced chlorosis. In 2008, no chlorosis was observed at 7 DAT for any combination of soil N levels and imazamox rates.

There was no interaction between soil N levels and imazamox rates on sunflower seed yield (data not shown). Main effects for both factors were not significant (data not shown). Seed yield ranged from 790 to 1030 kg/ha in 2007 and from 1060 to 1910 kg/ha in 2008. Growing conditions affect phenology of plants such as flowering and ripening. Consequently, sunflower head moth attack in 2007 and seed predation by birds in both years affected seed yield discriminately among the treatments resulting in high variability within and among the treatments.

The height of the Palmer amaranth plants at the time of imazamox application seemed most important. Palmer amaranth in higher N treatments grew faster and reached the recommended growth threshold much sooner than plants in the low and mid-level N treatments. Recommended time of POST application of imazamox on *Amaranthus* spp. is before weeds reach 7.6 cm (Anonymous 2006). Soil N levels affected growth rate to the extent that weed differed between soil N levels at the time of herbicide application. Several studies have revealed a negative relationship between herbicide efficacy and plant size (Mayo et al. 1995; Sellers et al. 2009; Steckel et al. 1997). This study showed a positive relationship between N levels and the height of the Palmer amaranth plants. There appeared to be a tradeoff between the effect of soil

N level and plant height on imazamox efficacy. Consequently, greater plant height at the high soil N level nullified the effect of increased herbicide susceptibility of the plants.

The results provide a closer insight into the relationship between soil N level and imazamox rate on Palmer amaranth biomass reduction. There existed three unfavorable conditions for imazamox performance: (a) N-limited, (b) height-limited, and (c) both N- and weed height-limited. Except for the 2007 field study, none of the limitations were severe at the 56 kg/ha soil N level, thus resulting in was similar performance of both rates of imazamox. In 2007, despite larger Palmer amaranth plants, sufficient early-season precipitation and low weed density likely increased weed susceptibility to imazamox and nullified the negative effect of greater height on imazamox efficacy. Consequently, with only small difference in Palmer amaranth height, performance of the suboptimal rate tended to be closer to the recommended rate at the high soil N level. This implies that in high soil N environments the suboptimal and recommended rate would result in similar biomass reduction when applied before the weed exceeds recommended maximum height.

Sources of Materials

[1] Research Track Sprayer, De Vries Manufacturing, RR 1 Box 184, Hollandale, MN 56045.

[2] 80015LP TeeJet tip, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189.

[3] John Deere 7000 Max Emerge with finger-pickup planting units, Deere & Company World Headquarters, One John Deere Place, Moline, IL 61265.

[4] TT110015 TeeJet tip, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189.

[5] SAS statistical software, SAS Institute Inc. 100 SAS Campus Drive, Cary, NC 27513.

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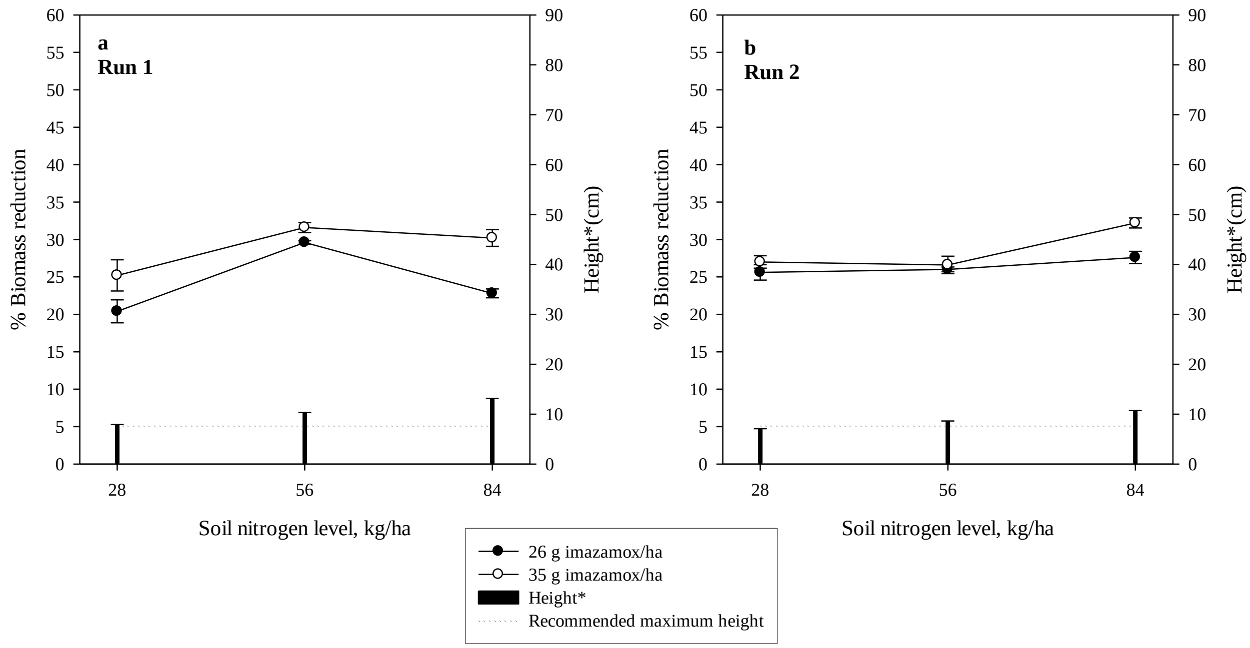

Figure 1.1. Mean percent Palmer amaranth biomass reduction as a function of soil N levels and imazamox rates in greenhouse experiments Run 1 (a) and Run 2 (b), Manhattan, KS.

*Height measured at the time of imazamox application.

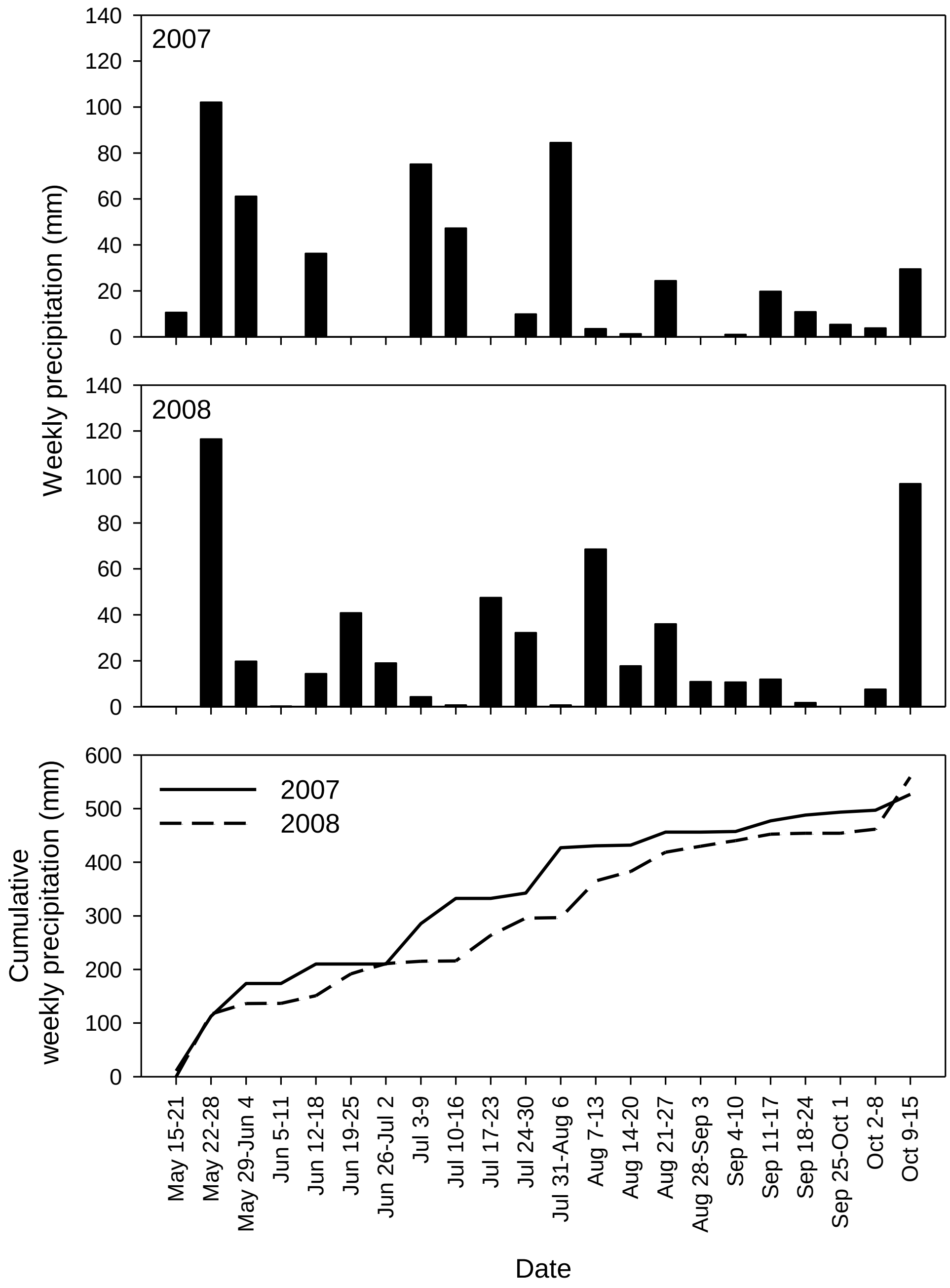

Figure 1.2. Weekly and cumulative precipitation during the growing season (May 15-Oct 15) in 2007 and 2008 at Kansas State University Agricultural Research Center, Hays, KS.

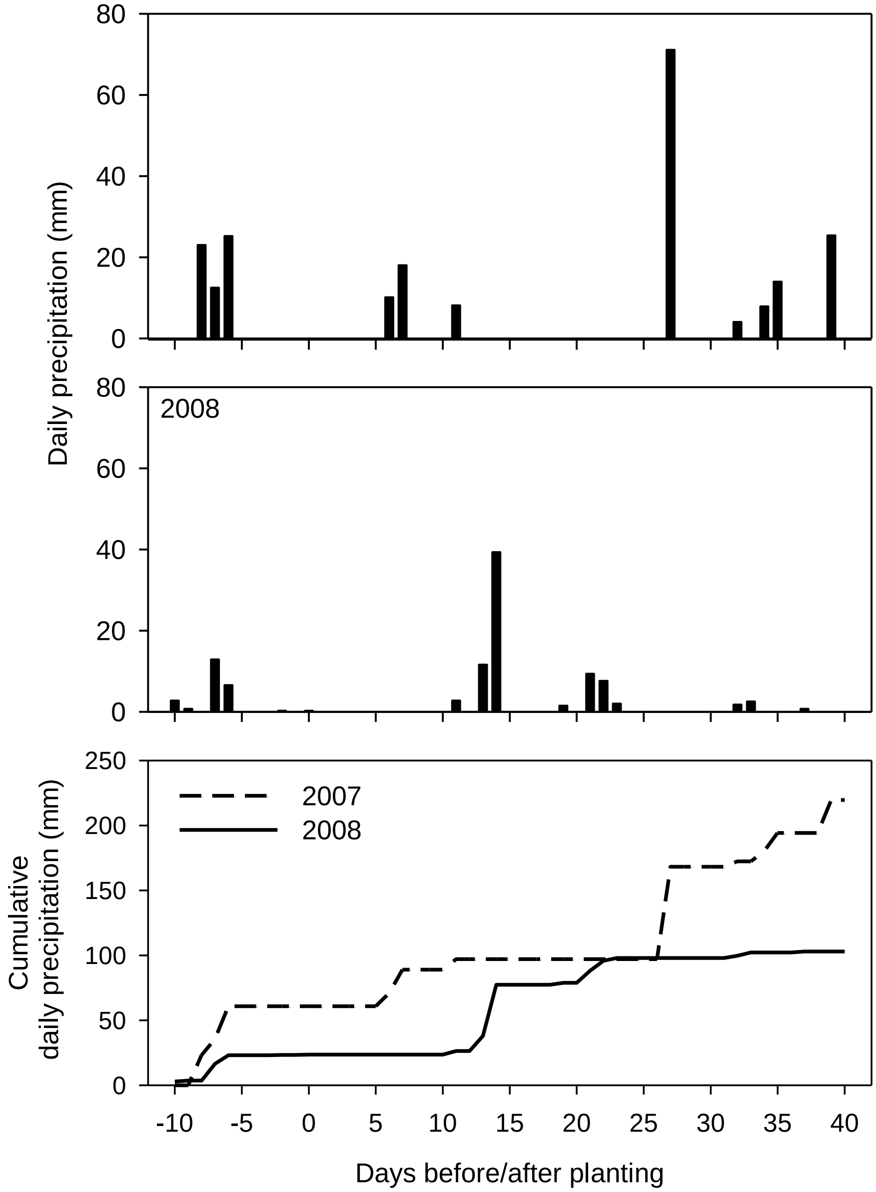

Figure 1.3. Daily and precipitation from 10 days before through 40 days after sunflower planting near Hays, KS. Sunflower was planted on June 7 in 2007 and June 5 in 2008, Hays, KS.

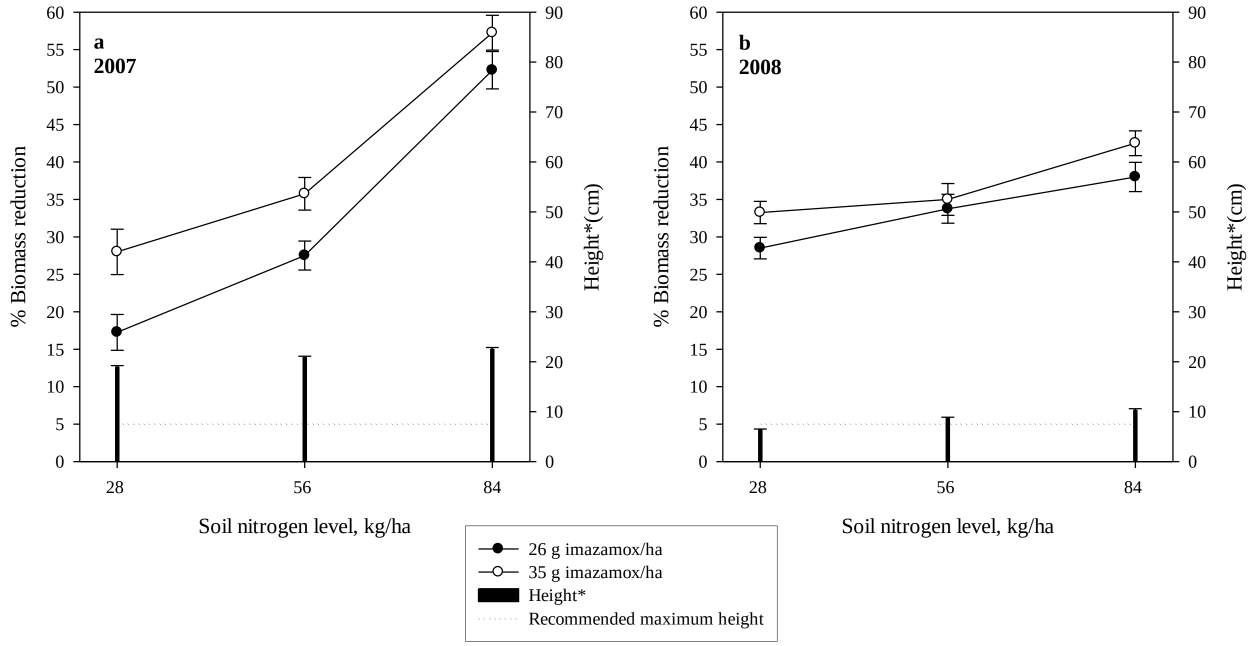

Figure 1.4. Mean percent Palmer amaranth biomass reduction as a function of soil N levels and imazamox rates in field experiments 2007 (a) and 2008 (b), Hays, KS.

*Height measured at the time of imazamox application.

Table 1.1. P-values from the analysis of variance (ANOVA) for percent biomass reduction of Palmer amaranth.

Study	Sources of Variation		
	Nitrogen	Herbicide	Nitrogen x Herbicide
Greenhouse experiment			
Run 1	<.0001	<.0001	2.4900
Run 2	0.0003	0.0018	0.0950
Field experiment			
2007	<.0001	0.0007	0.5037
2008	0.0004	0.0274	0.5605

CHAPTER II

WEED CONTROL AND CROP RESPONSE IN TRIBENURON-TOLERANT SUNFLOWER

ABSTRACT

Two field experiments were conducted near Hays, KS in 2007 and 2008 to evaluate the effects of single and sequential postemergent applications of tribenuron on broadleaf weed control and crop response and to assess the effectiveness of various treatments of preemergence herbicides followed by tribenuron applied postemergence in tribenuron-tolerant sunflower. Weeds were ALS-susceptible biotypes of kochia, puncturevine, Russian thistle, and tumble pigweed in 2007 and puncturevine, redroot pigweed, and tumble pigweed in 2008. Tribenuron at 18 g/ha applied early-POST with MSO provided >96% control of all species in 2007 and 92% control of redroot pigweed, but only 69% control of tumble pigweed in 2007. Early-POST tribenuron at 9 g/ha and late-POST tribenuron at 18 g/ha generally provided less weed control compared to early-POST tribenuron at 18 g/ha. Sequential applications slightly improved redroot pigweed and tumble pigweed control in 2008 compared to single application of tribenuron. The PRE/POST treatments provided little or no better control of kochia, puncturevine, and Russian thistle compared to POST tribenuron alone. However, PRE sulfentrazone at 140 g/ha and *S*-metolachlor at 1400 g/ha followed by either rate of POST tribenuron improved tumble pigweed control by at least 13 and 20% compared to POST tribenuron at 18 g/ha in 2007 and 2008, respectively. Among PRE herbicides, sulfentrazone generally controlled broadleaf weeds better than pendimethalin or *S*-metolachlor. Some tribenuron treatments caused transitory crop injury, but imazamox at 35 g/ha caused 24 to 44% crop injury at 7 DAT and permanent crop stunting in 2007. Significant yield loss occurred with imazamox and single treatments of tribenuron in 2008. Collectively, early-POST tribenuron at 18 g/ha with MSO adjuvant alone can provide satisfactory control of the evaluated broadleaf weed species without significant injury to tribenuron-tolerant sunflower.

Nomenclature: *S*-metolachlor; pendimethalin; quizalofop; sulfentrazone; tribenuron; kochia, *Kochia scoparia* (L.) Schrad.; puncturevine, *Tribulus terrestris* L.; redroot pigweed, *Amaranthus retroflexus* L.; Russian thistle, *Salsola iberica* (Sennen & Pau) Botch. ex; tumble pigweed, *Amaranthus albus* L.; sunflower, *Helianthus annuus* L. ‘Pioneer 63N81 or 63N82’.

Keywords: crop injury, sequential application, tribenuron-tolerant sunflower, weed control.

Abbreviations: COC, crop oil concentrate; MSO, methylated seed oil; NIS, nonionic surfactant; DAT, days after treatment.

Introduction

Sunflower is an important cultivated crop in the northern and central Great Plains of the United States. Sunflower tolerates drought better than most other row crops grown in the region because of its deep rooting pattern and ability to extract soil water and nutrients from deeper in the soil profile than sorghum, corn, pearl millet or soybean (Hattendorf et al. 1988). Unger (1984) reported that sunflower extracted soil water from as deep as 3 m, whereas under similar conditions sorghum extracted water to a depth of 1.2 m.

Sunflower usually is planted in widely-spaced rows about the same time many summer annual weeds normally emerge (Anderson and Nielsen 1996). Crop canopy closure often does not occur until mid-season, thus making the crop vulnerable to interference from grass and broadleaf weeds that emerge during the early period of sunflower growth. The competitive advantage of sunflower with later emerging weeds is greater than with weeds that emerge simultaneously or soon after crop emergence. Early emerging weeds competing longer than four weeks may interfere with sunflower and cause substantial yield loss (Johnson 1971).

Sunflower's ability to extract soil water from deeper in the soil profile than other crops increases the chances of yield reduction in crops following sunflower, especially in dry years (Nielsen et al. 1999). The situation may be aggravated by high weed density in sunflower fields. Dicot weeds generally present a more serious problem than monocots (Lamey et al. 1999). The most common and troublesome weeds in sunflower fields in the central Great Plains include pigweed species (*Amaranthus* spp.), kochia [*Kochia scoparia* (L.) Schrad.], and Russian thistle (*Salsola iberica* Sennen and Pau) (Lamey et al. 1999). These weed flora have been traditionally controlled with preemergence (PRE) herbicides because of the lack of postemergence (POST) broadleaf herbicides. Most POST herbicides labeled for use in sunflower control a narrow spectrum of grass weeds (Miller and Alford 2000). POST-applied imazamox controls both grass and broadleaf species but imazamox can only be used in imidazolinone-tolerant cultivars.

Tribenuron is a sulfonylurea herbicide that inhibits acetolactate synthase (ALS), a key enzyme in the branched chain amino acid pathway that produces leucine, isoleucine, and valine (Duke 1990). Inhibition of ALS leads to plant death primarily because of amino acid starvation (Shaner et al. 1984). Tribenuron has been used successfully for broadleaf control in wheat for several years and recently was registered for POST broadleaf control in tribenuron-tolerant sunflower. Application of tribenuron to conventional sunflower varieties will result in significant crop injury or plant death (Anonymous 2009). Moreover, sunflower lines developed to resist some ALS-inhibiting herbicides are also susceptible to foliar applications of other ALS-inhibiting herbicides (Howatt and Endres 2006) such as imazamox.

Crop varieties developed to survive herbicides normally lethal to the crop are attractive options because of the simplicity of the herbicide system (Shaner 2000). With herbicide-tolerant crop technology, broadleaf weeds can be controlled effectively in crops such as sunflower for which there are limited broadleaf weed control options, especially in minimum and no-till production systems. Because tribenuron-tolerant sunflowers are a recent development, there is need to evaluate tribenuron’s effectiveness in controlling weeds and crop response in tribenuron-tolerant sunflower.

Jones and Christians (2007) reported that greater control of creeping bentgrass was achieved with sequential applications of mesotrione at reduced rates compared to single higher-rate applications. Similarly, several studies have found that residual PRE herbicides followed by POST herbicides improved control of some species (Dirks et al. 2000; Gonzini et al. 1999;

Krausz and Young 2003). Development of herbicide resistant weed biotypes could also be prevented or delayed by applying herbicides with different modes of action (Krausz and Young 2003).

The hypothesis are that 1) sequential applications of tribenuron at reduced rates may improve weed control and crop safety in tribenuron-tolerant sunflower compared to single POST tribenuron treatments, and 2) tribenuron treatments applied following PRE herbicides may improve weed control as compared to tribenuron alone in tribenuron tolerant sunflower. Therefore, objectives of this research were to 1) evaluate the effect of single and sequential applications of tribenuron on weed control and crop response and 2) to access the effectiveness of various treatments of PRE herbicides followed by tribenuron applied POST in tribenuron-tolerant sunflower.

Material and Methods

Two field experiments were conducted in 2007 and 2008 at the Kansas State University Agricultural Research Center near Hays in west-central Kansas. Soil was a Crete silty clay loam (fine, montmorillonitic, mesic Pachic Argriustolls) with pH 6.5 and 2% organic matter. Experiments were a randomized complete block design with four replications. Plots were 3 by 10 m and encompassed four sunflower rows spaced 76 cm apart. Soil was tilled with a chisel plow, tandem disk or field cultivator as needed following the preceding crop and with a mulch treader prior to planting. Tribenuron-tolerant sunflower was planted at 61,750 seeds/ha on June 12, 2007 and July 1, 2008. ‘Pioneer 63N81’ variety was used in 2007 and ‘Pioneer 63N82’ variety was used in 2008. A mixture of broadleaf weed seeds collected from ALS-susceptible biotypes was broadcast immediately after crop planting in 2007 and two weeks prior to seeding in 2008.

Herbicide treatments were applied with a CO_2-pressurized backpack sprayer equipped with TT110015 tips[1] delivering 120 L/ha spray volume at 220 kPa. Dates, environmental conditions, and crop growth stages at the time of herbicide application are shown in Table 2.1 and weed growth stages are shown in Table 2.2. In both years, 80% of sunflower seeds emerged approximately one week after seeding resulting in established populations of 49,400 plants/ha.

Weed control ratings were based on composite visual estimations of density reduction, growth inhibition, and foliar injury using a scale of 0 (no effect) to 100 (plant death). Similarly, crop stunting, chlorosis, and malformation were rated visually at 7, 14 and 21 days after treatment (DAT) for POST treatments in both years. Height of 10 plants from the two center rows of plots was measured 8 weeks after planting (WAP). Seed yield was determined by harvesting the two center rows of each plot with a combine and adjusting seed weight to 10% moisture content.

Experiment I. Herbicide treatments included tribenuron at 9 and 18 g/ha applied 3 WAP, tribenuron at the higher rate applied 4 WAP, and sequential applications of tribenuron at both rates and timings. Also, imazamox at 35 g/ha was applied 3 WAP. Experiments included weed-free and untreated controls. Methylated seed oil (MSO) at 1% v/v was included in all herbicide treatments. Crop and weed growth stages at time of herbicide application are shown in Tables 2.2 and 2.3, respectively. Tribenuron treatments were tank mixed with quizalofop (61 g/ha) to control grass weeds.

Weeds emerged 3 to 4 days later than the crop in 2007 and 4 to 5 days earlier than crop emergence in 2008. Consequently, at the time early-POST treatments were applied, sunflower plants were taller than the weeds in 2007 and shorter than the weeds in 2008. Weed species composition and density differed between years with only tumble pigweed and puncturevine present in both years. Kochia, puncturevine, Russian thistle, and tumble pigweed at densities of 3, 2, 10, and 2 plants/m^2 were present in 2007. Puncturevine, redroot pigweed, and tumble pigweed at densities of 2, 4, and 9 plants/m^2 were present in 2008.

Experiment II. Treatments consisted of two rates of tribenuron (9 and 18 g/ha) applied POST alone and following labeled rates of PRE-applied pendimethalin, sulfentrazone or *S*-metolachlor. Weed-free and untreated controls were included for comparison. Crop oil concentrate (COC) at 1% v/v or nonionic surfactant (NIS) at 0.25% v/v was included in all POST treatments in 2007 and 2008, respectively. Use of NIS instead of COC in 2007 was an inadvertent change that may have affected results. PRE herbicides were applied immediately after crop planting in 2007, but 2 weeks preplant in 2008. The reason for this disparity was that sunflowers were reseeded in 2008 because of poor stand establishment as a result of heavy rainfall and soil crusting. POST treatments were applied 3 WAP in both years. Dates and environmental condition at the time of herbicide application as well as crop and weed growth stage are shown in Tables 2.2 and 2.3, respectively. Weeds were the same as described for experiment I.

Statistical Analysis. All data were subjected to analysis of variance and treatment means were separated using Fisher's protected LSD at $P < 0.05$ level. Analysis of variance was performed with the Agricultural Research Manager (ARM) 7. Transformation of visually derived data did not affect analyses, thus nontransformed values are shown. Because of differences in weed species in 2007 and 2008, weed control estimates were not pooled over years. Therefore, data are presented and discussed separately by year.

Results and Discussion

Total seasonal precipitation was similar in both years but rainfall patterns 10 days before through 20 days after sunflower planting differed considerably between years (Figures 2.1 and

2.2), which, in turn, affected time of sunflower planting and crop and weed emergence. As a result, heights of sunflower and weed species at the time of POST herbicide application differed between years (Tables 2.1 and 2.2). Weed species composition and density also differed between years. These factors likely explain differences in weed control and crop response between the two years.

Weed control for PRE herbicides was rated 24 and 30 DAT in 2007 and 2008, respectively. Weed control in 2007 had peaked 3 weeks after early-POST treatment (WAEPT) in experiment I and 3 weeks after POST treatment (WAPT) in experiment II, whereas in 2008, control of most species did not peak until 4 WAEPT or WAPT. Therefore, results for POST treatments are discussed based on weed control at 3 WAEPT in 2007 and 4 WAEPT in 2008.

Experiment I. Tribenuron at 18 g/ha early-POST, imazamox at 35 g/ha early-POST, and all sequential tribenuron treatments controlled tumble pigweed 96% or more at 3 WAEPT in 2007 (Table 2.3). In comparison, tribenuron at 9 g/ha early-POST and tribenuron at 18 g/ha late-POST controlled tumble pigweed 80%. These results were similar to those in the southern Great Plains reported by Harbour et al. (2007).

In 2008, none of the tribenuron treatments exceeded 84% control of tumble pigweed at 4 WAEPT (Table 2.3). Control was largely due to growth inhibition with less density reduction than occurred in 2007. The probable reason for the lower control is that tumble pigweed plants were seven or more cm taller in 2008 than in 2007 at the time of early-POST application (Table 2.2). The sequential treatment of 18 g/ha tribenuron early-POST followed by 9 g/ha tribenuron late-POST, and imazamox at 35 g/ha early-POST controlled tumble pigweed 84 and 83% , respectively, compared to 58 to 76% control with all the other tribenuron treatments (Table 2.3). The sequential treatment of 9 g/ha tribenuron early-POST followed by 9 g/ha tribenuron late-POST was similarly effective as a single early-POST application of tribenuron at 18 g/ha, but the sequential treatment was more effective than the single higher rate application of tribenuron applied late-POST.

Puncturevine control at 3 WAEPT in 2007 was >95% for all tribenuron treatments except the late-POST application, which provided only 74% control (Table 2.3). In 2008, all tribenuron treatments controlled puncturevine >98%. Puncturevine control with 35 g/ha of imazamox was 80% in 2007 and 28% in 2008. Puncturevine plants were considerably larger at the time of imazamox application in 2008 compared to 2007, which probably explains the poor control achieved in 2008.

Kochia and Russian thistle were present only in 2007 and redroot pigweed was present only in 2008. Early-POST application of tribenuron at 18 g/ha and all the sequential applications provided 91% or greater control of kochia and redroot pigweed at 3 and 4 WAEPT, respectively, and at least 98% control of Russian thistle at 3 WAEPT (Table 2.4). In comparison, tribenuron applied early-POST at 9 g/ha was at least 20% less effective in controlling kochia and redroot pigweed, but was similarly effective with higher rate and sequential treatments in controlling Russian thistle. Furthermore, tribenuron applied only late-POST at 18 g/ha, as well as imazamox applied early-POST at 35 g/ha, were less effective in controlling kochia and Russian thistle. However, both of those treatments controlled redroot pigweed as well as all sequential tribenuron treatments.

These findings generally agree with results reported by Harbour et al. (2007) that these and other species were controlled best when tribenuron was applied sequentially, except in this study both single application tribenuron treatments controlled Russian thistle as effectively as sequential tribenuron treatments.

In 2007, most tribenuron treatments caused slight chlorosis (≤6%) and stunting (≤5%) at 7 DAT but neither effect was evident at 21 DAT (data not shown). Tribenuron did not visibly injure the sunflowers in 2008. At maturity in 2007, of all the tribenuron treatments only sunflower receiving 18 g/ha tribenuron late-POST were shorter (4%) than untreated sunflowers (Table 2.5). Thompson et al. (2007) also observed minor tribenuron-induced chlorosis in a similar study in far western Kansas in 2007, but the effect was temporary and the growth and development of tribenuron-tolerant sunflower was not affected.

Imazamox severely injured tribenuron-tolerant sunflowers in 2007, but was less injurious in 2008. Imazamox at 35 g/ha applied early-POST caused 31, 24, and 44% crop stunting, chlorosis, and malformation, respectively, at 7 DAT in 2007 (Figure 2.3a). At the same interval in 2008, that treatment caused 7, 8, and 10% stunting, chlorosis, and malformation, respectively (Figure 2.3b). Injury symptoms decreased gradually in both years and chlorosis had disappeared at 21 DAT, but sunflower plants remained shorter than untreated sunflowers throughout the season, especially in 2007 (Figure 2.3a). At maturity, imazamox-treated tribenuron-tolerant sunflowers were 8 to 10% shorter than untreated sunflowers (Table 2.6).

Sunflower seed yields in 2007 ranged from 1870 to 2340 kg/ha and were unaffected by herbicide treatments (Table 2.5). In 2008, hand weeded sunflowers and those receiving sequential tribenuron treatments produced similar seed yields of 1790 to 2080 kg/ha. Seed yield of sunflowers receiving single tribenuron treatments, regardless of rates or timings, yielded considerably less at 1170 to 1330 kg/ha. Seed yields of imazamox-treated and untreated sunflowers were 78 and 60% lower, respectively, compared with the yield of weed-free sunflowers.

Tribenuron's effectiveness in controlling weeds is affected by rate, frequency and time of tribenuron application as well as weed size. The 9 g/ha rate of tribenuron controlled Russian thistle and puncturevine as well as the 18 g/ha rate when applied early-POST and the late-POST application was more effective on redroot pigweed. Either the higher tribenuron rate applied early-POST or sequential applications of tribenuron were required to achieve excellent control of kochia and tumble pigweed. Similarly, in a multi-state study, Harbour et al. (2007) reported that kochia, Palmer amaranth, Russian thistle, and puncturevine were controlled best with sequential tribenuron applications.

Experiment II. Tumble pigweed control with PRE-applied sulfentrazone at 140 g/ha and *S*-metolachlor at 1400 g/ha averaged 97 and 99% at 24 DAT in 2007, and 84 and 85% at 30 DAT in 2008. Both herbicides provided at least 10% greater tumble pigweed control in 2007 and 20% greater control in 2008 than PRE-applied pendimethalin at 920 g/ha. POST-applied tribenuron at 9 and 18 g/ha controlled tumble pigweed 64 and 85%, respectively, at 3 WAPT in 2007 and 50 and 70%, respectively, at 4 WAPT in 2008 (Table 2.6). Either rate of POST tribenuron supplemented with PRE sulfentrazone or *S*-metolachlor improved control of tumble pigweed at least 13 and 20% in 2007 and 2008, respectively.

Of the weed species evaluated, the PRE herbicide treatments were least effective on puncturevine. Puncturevine control with 140 g/ha of sulfentrazone averaged 90% at 24 DAT in 2007, but neither 920 g/ha of pendimethalin nor 1400 g/ha of *S*-metolachlor controlled puncturevine by as much as 50% in 2007, and none of the three PRE herbicides controlled puncturevine by as much as 50% at 30 DAT in 2008. In comparison, POST-applied tribenuron at 9 and 18 g/ha without benefit of a PRE herbicide treatment controlled puncturevine 98 and 97%, respectively, at 3 WAPT in 2007, and 100% at 4 WAPT in 2008.

Kochia and Russian thistle were present only in 2007 and redroot pigweed was present only in 2008. Kochia control with PRE-applied pendimethalin at 920 g/ha, sulfentrazone at 140 g/ha, and *S*-metolachlor 1400 g/ha was 88 to 99% at 24 DAT. PRE-applied sulfentrazone at 140 g/ha controlled Russian thistle 93% at 24 DAT, and the control was 69 and 47% less with PRE-applied pendimethalin at 920 g/ha and *S*-metolachlor at 1400 g/ha, respectively. Redroot pigweed control averaged 93 and 87% with the same rates of sulfentrazone and *S*-metolachlor, respectively, but 30% less with the same rate of pendimethalin compared to sulfentrazone at 30 DAT.

Tribenuron applied POST at 9 and 18 g/ha alone controlled kochia and Russian thistle as well as when applied following PRE treatments (Table 2.7). Control ranged from 92 to 94% for kochia and 97 to 98% for Russian thistle. However, POST-applied tribenuron at 9 g/ha controlled redroot pigweed only 80% at 4 WAPT which was at least 8% less compared to the higher rate of tribenuron alone and the both tribenuron treatments followed by PRE-applied pendimethalin. Both tribenuron treatments supplemented with PRE-applied sulfentrazone and *S*-metolachlor slightly (≤5%) improved redroot pigweed control compared to the higher rate of tribenuron alone.

None of the PRE treatments visibly injured sunflower at 24 and 30 DAT in 2007 and 2008, respectively (data not shown). In contrast to results from a trial in Texas (Harbour et al. 2007), sulfentrazone did not cause any crop injury in this experiment. Sulfentrazone may injure sunflowers grown in soils with low cation exchange capacity (CEC) (Kerr et al. 2004). Low CEC is a characteristic of high pH, coarse textured, and low organic matter soils which was not the case in this experiment. Tribenuron treatments in 2007 caused ≤11% chlorosis and ≤9% stunting at 7 DAT and disappeared completely at 21 DAT (data not shown).

No significant differences in sunflower height were observed among the treatments in either year at 8 WAP (Table 2.8). In 2007, sunflower seed yield ranged from 2020 to 2290 kg/ha with no difference among the treatments. Late emergence of weeds relative to crop emergence and low competitiveness of the predominant weed species resulted in no yield differences among the treatments. In 2008, both rates of tribenuron applied following PRE-applied sulfentrazone at 140 g/ha or *S*-metolachlor at 1400 g/ha produced the highest seed yields of 1940 to 2010 kg/ha. However, the same tribenuron treatments applied following pendimethalin at 920 g/ha and hand weeded treatments yielded1430 to1590 kg/ha. Because of early weed emergence at the high density relative to crop emergence in 2008 and three weeks of crop-weed competition prior to weed removal, weed interference occurred in hand weeded plots resulting in reduced sunflower yield. Either rate of tribenuron applied alone did not improve seed yield compared with untreated check and seed yield ranged from 1270 to 1300 kg/ha.

Among the PRE herbicides, sulfentrazone provided broader spectrum of weed control than *S*-metolachlor and especially pendimethalin. However, sunflower yields were similar in 2008 for sulfentrazone and *S*-metolachlor treatments; both were higher than pendimethalin (Table 2.8). Pendimethalin controlled only kochia >90% and provided only fair to good control (65 to 86%) of tumble pigweed. *S*-metolachlor provided excellent control of tumble pigweed only in 2007. Tribenuron alone, especially at the high rate, provided good control of kochia, puncturevine, redroot pigweed, and Russian thistle, but not tumble pigweed in either year. Tumble pigweed control was good when tribenuron was applied following PRE herbicide treatments in 2007; however, the control was largely due to PRE herbicides alone. In 2008, PRE herbicides and tribenuron, especially at the high rate, together provided good control of tumble pigweed.

Overall weed control was less in 2008 than in 2007 with both PRE and POST herbicide treatments. Possible reasons included the greater interval between PRE herbicide application to time of first rating because of replanting, the later emergence of weeds relative to time of PRE application, size of the weeds at the time POST application, and possible differences in control effectiveness between adjuvants (Zollinger 2005). The inadvert use of NIS instead of COC with tribenuron in 2007 may have contributed to reduced tribenuron performance. Tribenuron treatments caused transitory crop injury in 2008 without affecting crop height. In conclusion, need of supplemental PRE herbicides for weed control in tribenuron-tolerant sunflower depends on weed species present and their size at the time of tribenuron application.

This study demonstrated that tribenuron effectively controls ALS-susceptible biotypes of several of the major broadleaf weeds infesting sunflower fields in the central Great Plains. The study also confirmed that tribenuron-tolerant sunflower lacks tolerance to POST-applied imazamox; crop injury was severe. Thus, the herbicide tolerance trait is specific to tribenuron and does not confer cross tolerance to other ALS-inhibiting herbicides. Furthermore, applying a PRE herbicide, particularly sulfentrazone or *S*-metolachlor reduces the risk of tribenuron not controlling ALS-resistant weed biotypes that might be present and of poor tribenuron performance because of weed size or adverse climatic conditions.

The small improvement in control of some species achieved with sequential tribenuron applications likely not enough to off-set the additional cost and inconvenience of a second application compared to results of a timely single application at full rate. None of the tribenuron treatments caused more than transitory chlorosis and stunting, thus indicating flexibility in the timing of tribenuron applications. However, for best results, this study indicates tribenuron should be applied based on weed size rather than crop stage.

Limitations

Tribenuron does not control ALS-resistant biotypes of weed species. In Kansas, resistance to ALS- inhibiting herbicides has been confirmed in kochia, Russian thistle, and some pigweed species (Peterson 1999). In fields with suspected or known populations of ALS-resistant weeds, growers should apply a non-ALS-inhibiting PRE herbicide and not rely on a total POST tribenuron or imazamox herbicide program. Repeated use of herbicides with the same mode of action herbicides imposes selection pressure on the weed population and may limit the use of other ALS-inhibiting herbicides in other crops grown in rotation.

Sources of Materials

[1]TT110015 TeeJet tip, Spraying Systems Co. P. O. Box 7900, Wheaton, IL 60189.

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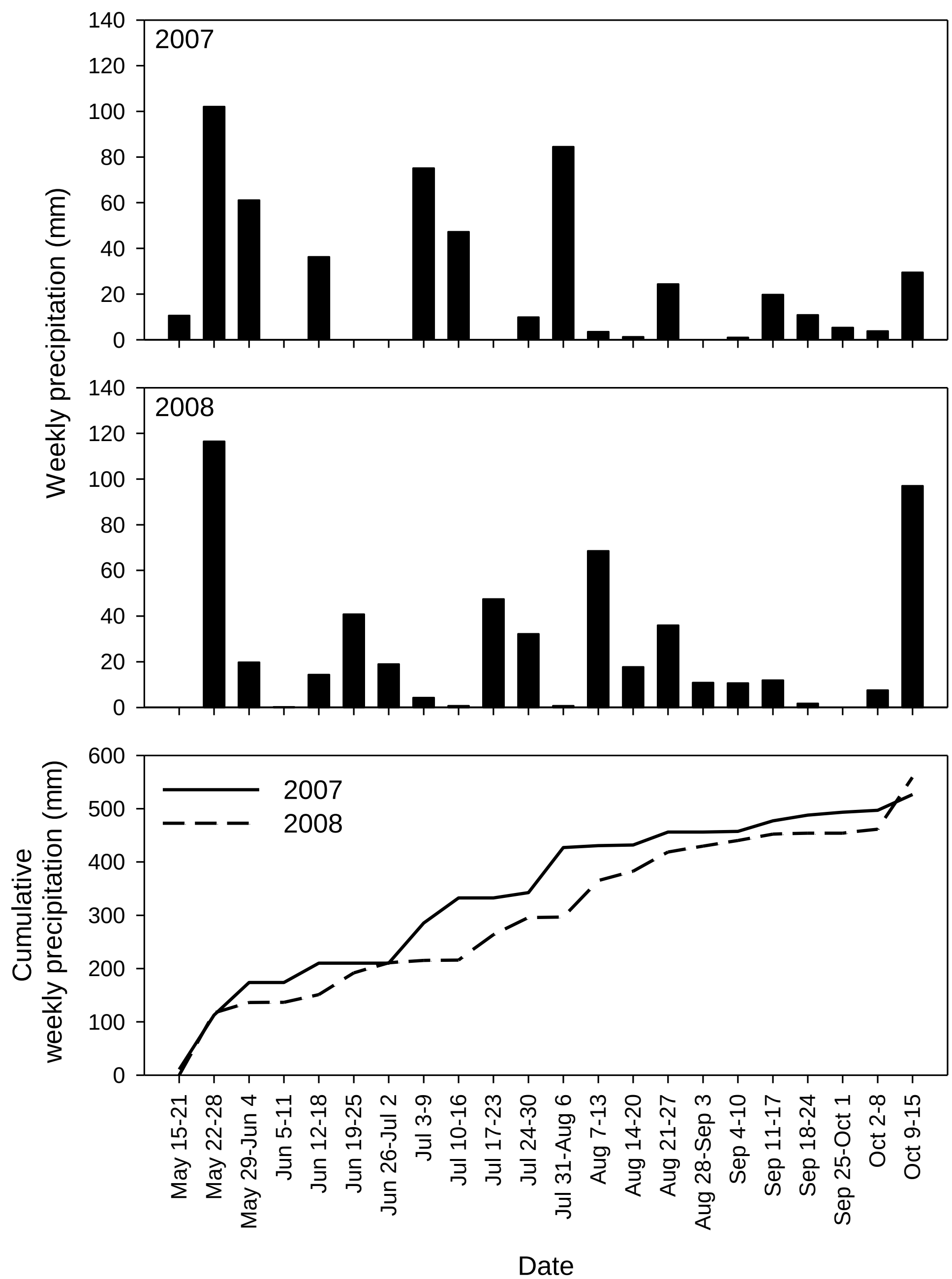

Figure 2.1**.** Weekly and cumulative precipitation during the growing season (May 15-Oct 15) in 2007 and 2008 at Kansas State University Agricultural Research Center, Hays, KS.

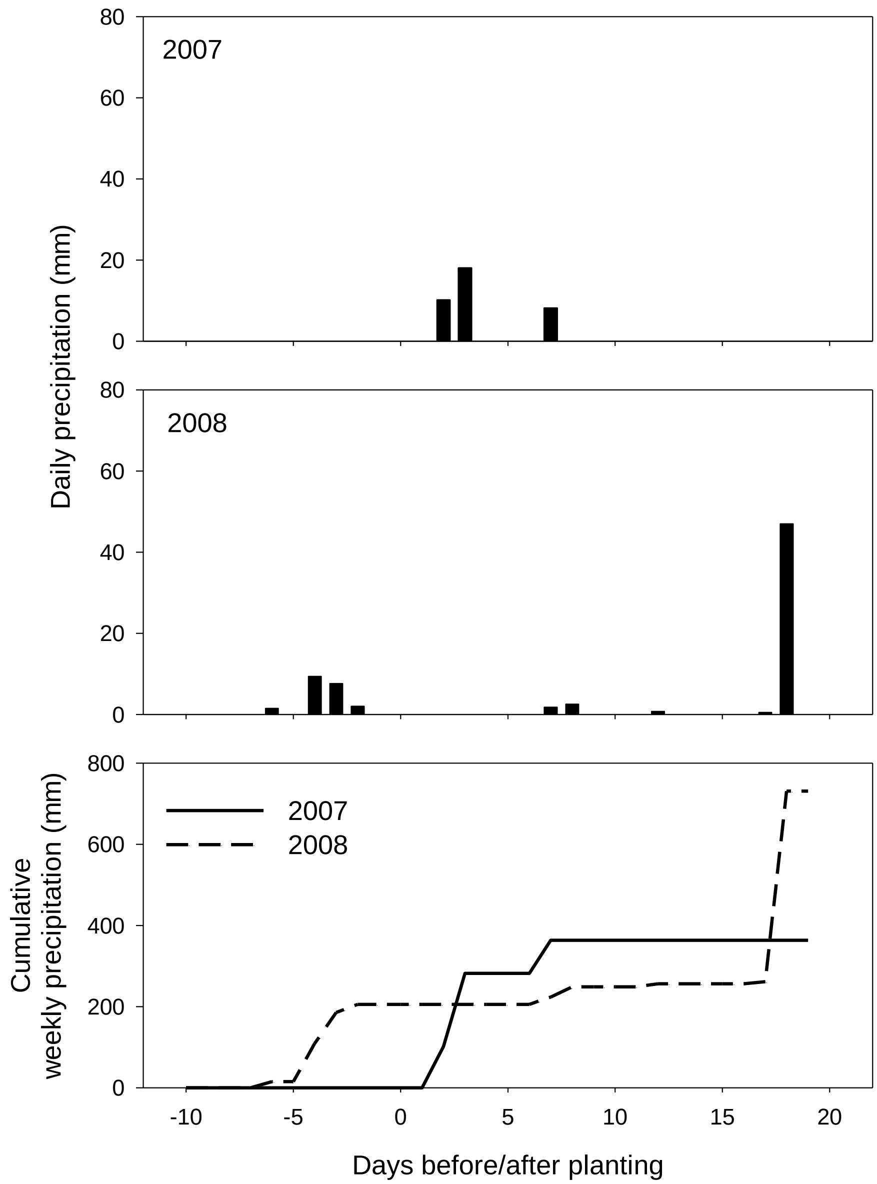

Figure 2.2. Daily and cumulative precipitation from 10 days before through 20 days after sunflower planting in 2007 and 2008 at Kansas State University Agricultural Research Center, Hays, KS.

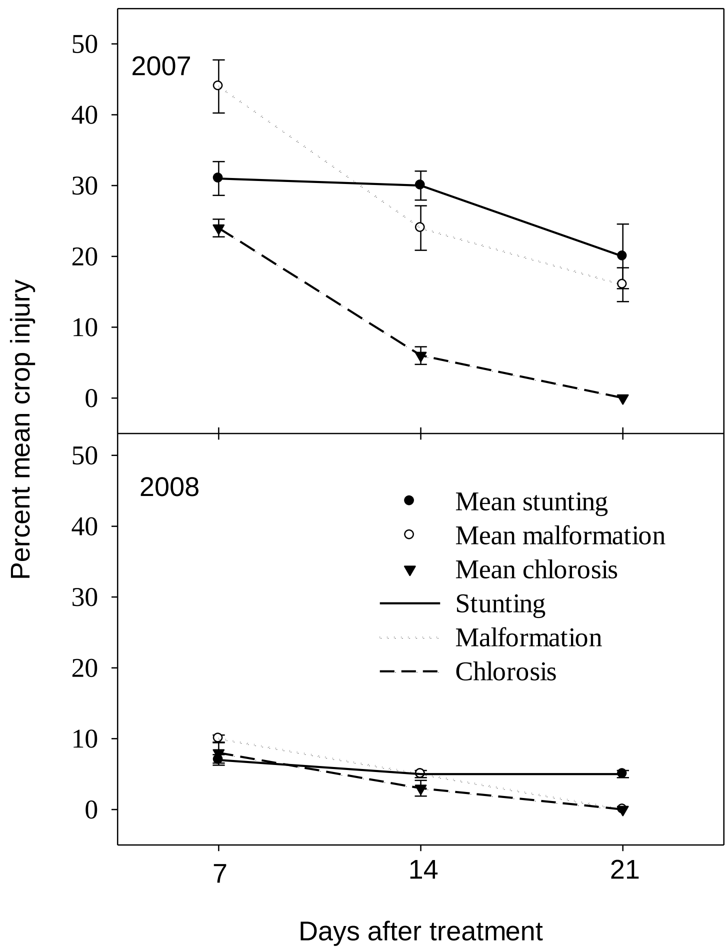

Figure 2.3. Tribenuron-tolerant sunflower response to 35 g/ha of imazamox applied with 1% v/v methylated seed oil at 7, 14, and 21 days after treatment, Hays, KS.

Table 2.1. Dates, environmental conditions, and sunflower growth stage and height at the time of herbicide application, Hays, KS.

		Temperature				Sunflower	
Date	Application	Air	Soil (1.3 cm)	Soil (5 cm)	RH	Stage	Height
			C		%		cm
Experiment I							
July 3, 2007	Early-POST	22	24	24	88	V6-V8	13-18
July 12, 2007	Late-POST	28	33	31	55	V10-V12	41
July 21, 2008	Early-POST	26	-	-	58	V4-V5	10-15
July 28, 2008	Late-POST	27	-	-	60	V5-V6	13-20
Experiment II							
June 12, 2007	PRE	28	31	24	55	PRE	0
July 6, 2007	POST	26	26	23	59	V8	20-25
June 17, 2008	PRE	21	23	22	58	PRE	0
July 21, 2008	POST	26	-	-	58	V4-V5	10-15

Abbreviations: PRE, preemergence; POST, postemergence.

Table 2.2. Weed height at the time of herbicide application, Hays, KS.

Date	Application	Weed species[a] AMAAL	AMARE	KCHSC	SASKR	TRBTE
		cm				
Experiment I						
July 3, 2007	Early-POST	5-8	-	5-10	8-15	5-10[b]
July 12, 2007	Late-POST	15-20	-	20	20-41	25-30[b]
July 21, 2008	Early-POST	15-30	15-38	-	-	25-38[b]
July 28, 2008	Late-POST	20-38	15-46	-	-	25-46[b]
Experiment II						
June 12, 2007	PRE	0	-	0	0	0
July 6, 2007	POST	10-15	-	10	10-15	10-25[b]
June 17, 2008	PRE	0	0	-	-	0
July 21, 2008	POST	15-30	15-38	-	-	25-38[b]

[a] Weed species are identified by Bayer code.
[b] vine diameter.

Abbreviations: AMAAL, tumble pigweed; AMARE, redroot pigweed; KCHSC, kochia; PRE, preemergence; POST, postemergence; SASKR, Russian thistle; TRBTE, puncturevine.

Note: Sunflowers were planted June 12, 2007 and July 1, 2008.

Table 2.3. Weed control in tribenuron-tolerant sunflower with single and sequential applications of tribenuron at 2 and 3 WAEPT in 2007 and 2, 3, and 4 WAEPT in 2008, Hays, KS.

		Weed species[a]									
		AMAAL					TRBTE				
		2007		2008			2007		2008		
		WAEPT									
Treatment[b] (application timing)	Rate[c]	2	3	2	3	4	2	3	2	3	4
	g/ha	%[d]									
Tribenuron (E)	9	76	80	54	55	58	91	95	92	96	98
Tribenuron (E)	18	97	99	63	63	69	96	98	93	97	99
Tribenuron (E) fb tribenuron (L)	9 fb 9	93	96	74	79	71	94	97	91	97	99
Tribenuron (E) fb tribenuron (L)[e]	9 fb 18	-	-	76	78	76	-	-	85	95	99
Tribenuron (E) fb tribenuron (L)	18 fb 9	95	96	88	83	84	97	97	93	98	99
Tribenuron (E) fb tribenuron (L)[f]	18 fb 18	99	99	-	-	-	97	99	-	-	-
Tribenuron (L)	18	85	80	61	59	63	50	74	24	34	98
Imazamox (E)	35	99	99	81	76	83	80	82	31	35	28
LSD (0.05)		6	7	6	6	5	5	4	5	6	5

[a] Weed species are identified by Bayer code.
[b] All the treatments included 1% v/v methylated seed oil (MSO) and all the single and late-POST tribenuron treatments were supplemented with 61 g/ha of quizalofop for grass control.
[c] Multiple rates follows the same order as treatments in the first column.
[d] Weed control based on density reduction (mortality), growth reduction, and injury.
[e] Treatment present only in 2008.
[f] Treatment present only in 2007.Abbreviations: AMAAL, tumble pigweed; E, early-POST; L, late-POST; TRBTE, puncturevine; WAEPT, weeks after early-POST treatment.

Table 2.4. Weed control in tribenuron-tolerant sunflower with single and sequential applications of tribenuron at 2 and 3WAEPT in 2007 and 2, 3 and 4 WAEPT in 2008, Hays, KS.

		Weed species[a]						
		KCHSC		SASKR		AMARE		
		2007		2007		2008		
		WAEPT						
Treatment[b] (application timing)	Rate[c]	2	3	2	3	2	3	4
	g/ha	%[d]						
Tribenuron (E)	9	62	67	97	98	71	70	73
Tribenuron (E)	18	95	96	99	99	89	88	92
Tribenuron (E) fb tribenuron (L)	9 fb 9	89	91	97	98	86	91	96
Tribenuron (E) fb tribenuron (L)[e]	9 fb 18	-	-	-	-	84	90	95
Tribenuron (E) fb tribenuron (L)	18 fb 9	94	94	99	98	92	96	97
Tribenuron (E) fb tribenuron (L)[f]	18 fb 18	96	97	99	99	-	-	-
Tribenuron (L)	18	64	66	84	90	76	84	96
Imazamox (E)	35	81	77	75	76	91	93	97
LSD (0.05)		7	7	4	3	5	5	3

[a] Weed species are identified by Bayer code.
[b] All the treatments included 1% v/v methylated seed oil (MSO) and all the single and late-POST tribenuron treatments were supplemented with 61 g/ha of quizalofop for grass control.
[c] Multiple rates follows the same order as treatments in the first column.
[d] Weed control based on density reduction (mortality), growth reduction, and injury.
[e] Treatment present only in 2008.
[f] Treatment present only in 2007.

Abbreviations: AMARE, redroot pigweed; E, early-POST; KCHSC, kochia; L, late-POST; SASKR, Russian thistle; WAEPT, weeks after early-POST treatment.

Table 2.5. Effect of single and sequential applications of tribenuron on tribenuron-tolerant sunflower height and seed yield in 2007 and 2008, Hays, KS.

Treatments[c] (application timing)	Rate[d]	Height[a]		Seed yield[b]	
		2007	2008	2007	2008
	g/ha	cm		kg/ha	
Tribenuron (E)	9	152	135	2340	1290
Tribenuron (E)	18	151	135	2330	1170
Tribenuron (E) fb tribenuron (L)	9 fb 9	150	135	2310	2080
Tribenuron (E) fb tribenuron (L)[e]	9 fb 18	-	134	-	1790
Tribenuron (E) fb tribenuron (L)	18 fb 9	153	136	2590	1960
Tribenuron (E) fb tribenuron (L)[f]	18 fb 18	150	-	2230	-
Tribenuron (L)	18	149	137	2280	1330
Imazamox (E)	35	138	130	1870	460
Untreated	-	155	141	2280	830
Weed-free	-	153	139	2330	2070
LSD (0.05)		5	5	NS	600

[a] Height measured approximately 8 weeks after planting.
[b] Seed yield adjusted to 10% moisture level.
[c] All the treatments included 1% v/v methylated seed oil (MSO) and all the single and late-POST applications of tribenuron were supplemented with 61 g/ha of quizalofop for grass control.
[d] Multiple rates follows the same order as treatments in the first column.
[e] Treatment present only in 2008.
[f] Treatment present only in 2007.

Table 2.6. Weed control in tribenuron-tolerant sunflower with tribenuron applied alone and following preemergence herbicides at 3 WAPT in 2007 and 3 and 4 WAPT in 2008, Hays, KS.

		Weed species[a]					
		AMAAL			TRBTE		
		2007	2008		2007	2008	
		WAPT					
Treatment[b] (application timing)	Rate[c]	3	3	4	3	3	4
	g/ha	%[d]					
Pendimethalin (PRE) fb tribenuron (POST)	920 fb 9	93	87	83	98	95	100
Pendimethalin (PRE) fb tribenuron (POST)	920 fb 18	94	88	87	99	95	100
Sulfentrazone (PRE) fb tribenuron (POST)	140 fb 9	98	94	91	99	95	100
Sulfentrazone (PRE) fb tribenuron (POST)	140 fb 18	99	96	95	99	96	100
S-metolachlor (PRE) fb tribenuron (POST)	1400 fb 9	99	95	90	99	93	100
S-metolachlor (PRE) fb tribenuron (POST)	1400 fb 18	99	95	91	99	95	100
Tribenuron (POST)	9	64	53	50	98	86	100
Tribenuron (POST)	18	85	66	70	97	89	100
LSD (0.05)		8	4	6	2	3	NS

[a] Weed species are identified by Bayer code.
[b] All the POST applications included 1% v/v crop oil concentrate (COC) in 2007 and non-ionic surfactant (NIS) 0.25% v/v in 2008.
[c] Multiple rates follows the same order as treatments in the first column.
[d] Weed control based on density reduction (mortality), growth reduction, and injury.

Abbreviations: AMAAL, tumble pigweed; POST, postemergence; PRE, preemergence; TRBTE, puncturevine; WAPT, weeks after POST treatment.

Table 2.7. Weed control in tribenuron-tolerant sunflower with tribenuron applied alone and following preemergence herbicides at 24 DAT and 3 WAPT in 2007 and 30 DAT and 3 and 4 WAPT in 2008, Hays, KS.

		Weed species[a]			
		KCHSC	SASKR	AMARE	
		2007	2007	2008	
		WAPT			
Treatment[b] (application timing)	Rate[c]	3	3	3	4
	g/ha	%[d]			
Pendimethalin (PRE) fb tribenuron (POST)	920 fb 9	98	95	91	88
Pendimethalin (PRE) fb tribenuron (POST)	920 fb 18	99	98	93	91
Sulfentrazone (PRE) fb tribenuron (POST)	140 fb 9	99	99	98	95
Sulfentrazone (PRE) fb tribenuron (POST)	140 fb 18	100	99	99	97
S-metolachlor (PRE) fb tribenuron (POST)	1400 fb 9	92	98	97	97
S-metolachlor (PRE) fb tribenuron (POST)	1400 fb 18	98	99	99	98
Tribenuron (POST)	9	94	97	61	80
Tribenuron (POST)	18	92	98	86	90
LSD (0.05)		NS	3	4	3

[a] Weed species are identified by Bayer code.
[b] All the POST applications included 1% v/v crop oil concentrate (COC) in 2007 and non-ionic surfactant (NIS) 0.25% v/v in 2008.
[c] Multiple rates follows the same order as treatments in the first column.
[d] Weed control based on density reduction (mortality), growth reduction, and injury.

Abbreviations: AMARE, redroot pigweed; KCHSC, kochia; POST, postemergence; PRE, preemergence; L; SASKR, Russian thistle; WAPT, weeks after POST treatment.

Table 2.8. Effect of tribenuron applied alone and following preemergence herbicides on tribenuron-tolerant sunflower height and seed yield in 2007 and 2008, Hays, KS.

		Height[a]		Seed yield[b]	
Treatment[c] (application timing)	Rate[d]	2007	2008	2007	2008
	g/ha	cm		kg/ha	
Pendimethalin (PRE) fb tribenuron (POST)	920 fb 9	154	136	2050	1430
Pendimethalin (PRE) fb tribenuron (POST)	920 fb 18	155	136	2130	1590
Sulfentrazone (PRE) fb tribenuron (POST)	140 fb 9	156	139	2290	2010
Sulfentrazone (PRE) fb tribenuron (POST)	140 fb 18	154	138	2280	1960
S-metolachlor (PRE) fb tribenuron (POST)	1400 fb 9	156	137	2260	1940
S-metolachlor (PRE) fb tribenuron (POST)	1400 fb 18	151	138	2215	1960
Tribenuron (POST)	9	156	136	2250	1270
Tribenuron (POST)	18	155	136	2230	1300
Untreated	-	160	138	2160	1210
Weed-free	-	-	137	-	1520
LSD (0.05)		NS	NS	NS	360

[a] Height measured approximately 8 weeks after planting.
[b] Seed yield adjusted to 10% moisture level.
[c] All the POST applications included 1% v/v crop oil concentrate (COC) in 2007 and 0.25% v/v non-ionic surfactant (NIS) in 2008.
[d] Multiple rates follows the same order as treatments in the first column.