EFFECT OF AIR TEMPERATURE, RELATIVE HUMIDITY AND GROWTH STAGE ON RIMSULFURON TOLERANCE IN SELECTED FIELD MAIZE HYBRIDS

Efecto de la temperatura del aire, de la humedad relativa y del estado de desarrollo de híbridos de maíz selectos sobre su tolerancia al rimsulfuron

Cilia L. Fuentes[1] and Gilles D. Leroux[2]

SUMMARY

The effect of temperature (T), relative humidity (RH), and growth stage (GS) of six field maize hybrids on the level of tolerance to rimsulfuron [N-((4,6-dimethoxypyrimidin-2-yl) aminocarbonyl)-3-(ethylsulfonyl)-2-pyridinesulfonamide] applied at 20, 40 and 60 g a.i. ha-1 were evaluated. The hybrids tested are adapted to three climatic zones of Québec, Canada (zone 1: >2 700 maize heat units (CHU); zone 2: 2 500 to 2 700 CHU; zone 3: 2 300 to 2 500 CHU). Two hybrids of each zone were considered. Three experiments were carried out under growth chamber and glasshouse conditions. Corn response to rimsulfuron doses was linear. Hybrids of zone 1 were more tolerant to rimsulfuron than hybrids from zones 2 and zone 3. Dry weight reduction of hybrids (DWR as a percentage of the untreated control 14 days after treatment) varied according to the dose from 22% to 29%, 31% to 35%, and 36% to 38% in zones 1, 2, and 3, respectively. The response of maize hybrids to increasing temperature was linear, and the DWR was 12%, 28%, and 51% at 14°C, 21°C, and 28°C, respectively. Injury to maize hybrids grown under 60% and 75% RH averaged 31% and 37% DWR, respectively.

Corn plants treated at the 2- to 3-leaf growth stage showed, in general, more sensitivity to rimsulfuron than those treated at the 4- to 5-leaf stage. These results confirm that both environmental conditions and maize genotypes play an important role in the injury caused by rimsulfuron.

Key words: herbicides, sulfonylurea, rimsulfuron, field maize hybrids, tolerance, environmental conditions.

Abbreviations: CHU, maize heat units; T, temperature; RH, relative humidity; GS, growth stage; DWR, dry weight reduction.

RESUMEN

Se evaluó el efecto de la temperatura (T), la humedad relativa (HR) y el estado de desarrollo (DE) de seis híbridos de maíz sobre su grado de tolerancia al herbicida rimsulfuron aplicado en dosis de 20, 40 y 60 g i.a. ha-1, en tres experimentos bajo condiciones de camaras de crecimiento e invernadero. Estos materiales de maíz están adaptados a tres zonas climáticas de Québec, Canada (zona 1: >2 700 UTM; zona 2: 2 500 a 2 700 UTM; zona 3: 2 300 a 2 500 UTM), y dos híbridos de cada una de las zonas fue considerado. La respuesta de los mteriales de maíz a dosis crecientes del rimsulfuron fue linear. Los híbridos de la zona 1 fueron más tolerantes al herbicida que los de lasm zonas 2 y 3. La reducción de la materia seca (RMS expresada como porcentaje del testigo sin tratar 14 días después de la aplicación del rimsulfuron) varió con relación a la dosis desde 22% a 29%, 31% a 35%, y 36% a 38% en los materiales de las zonas 1, 2 y 3, respectivamente. Igualmente, la respuesta de los híbridos al aumento de la temperatura fue linear; la RMS fue 12%, 28%, y 51% a 14°C, 21°C, y 28°C, respectivamente. Las plantas de maíz tratadas en estado de 2 a 3 hojas fueron en general, más sensibles al rimsulfuron, que aquellas tratadas en el estado de 4 a 5 hojas. Estos resultados confiman que tanto las condiciones ambientales como el genotipo, juegan un papel importante en la selectividad del rimsulfuron en maíz.

Palabras claves: herbicidas, sulfonylureas, rimsulfuron, híbridos de maíz, tolerancia, condiciones ambientales.

Abreviaciones: UTM, unidades térmicas maíz; T, temperatura; HR, humedad relativa; ED, estado de desarrollo; RMS, reducción de la materia seca.

INTRODUCTION

Selectivity of a herbicide depends on the inherent tolerance or susceptibility of a particular plant species or crop cultivar, the stage of growth of the plant, and the environment under which the plant is growing at the time of the herbicide treatment. The complexity of the situation derives from the interaction among above mentioned components, since no single component operates alone under field conditions (Malefyt and Quakenbush, 1991; Muzik, 1976; Smeda and Putnam, 1990). Effective use of selective postemergence herbicides requires manipulation of several factors, including herbicide dose, crop growth stage at the time of herbicide application, and environmental factors (Morton and Harvey, 1994).

- Fecha de recepcion 15 de febrero de 2002
- Aceptado para publicación 16 de diciembre de 2002

[1] Professor. Universidad Nacional de Colombia, Facultad de Agronomía, sede Bogotá. A.A. 14490, Bogotá, Colombia.
[2] Professor. Département de Phytologie, Faculté de Sciences de l'Agriculture et l'Alimentation, Université Laval, Ste. Foy, Québec, Canada.

The performance of many postemergence herbicides is greatly influenced by environmental conditions. Therefore, this topic has received special attention (Nalewaja *et al.*, 1975; Ritter and Coble, 1981; Wichert *et al.*, 1992). Most studies have concentrated on conditions at the time of herbicide application or during the period following foliar treatment (Blair *et al.*, 1983; Edmund and York, 1987; Fawcett *et al.*, 1987; Miller *et al.*, 1978; Miller *et al.*, 1984; Pillmoor, 1985; Ritter and Coble 1981; Wills and McWhorter, 1981). However, the pre-spray environment could also have an important effect on postemergence herbicide activity (Coupland, 1989). The manifestation of these effects depends upon interactions between the mode of action of the herbicide, the plant species, and the environmental factors under consideration (Coupland, 1989).

The effects of environmental factors on herbicide performance have been reviewed by Hammerton (1967) and Muzik (1976). Several studies indicate that air temperature (Blair *et al.*, 1983; Coupland, 1989; Edmund and York, 1987; Nalewaja *et al.*, 1990; Pillmoor, 1985; Smeda and Putnam, 1990; Xie *et al.*, 1994) and relative humidity (Chase and Appleby, 1979; Coupland, 1989; Ritter and Coble, 1981; Willingham and Graham, 1988; Wills and McWhorter, 1981; Wills, 1984) play an important role on the activity of postemergence herbicides. Within physiological limits, increased temperature generally causes increased activity of many herbicides (Coupland, 1983; Fawcett *et al.*, 1987; Kells *et al.*, 1984; Miller *et al.*, 1984; Smeda and Putnam, 1990; Wills and McWhorter 1981). In some cases, however, herbicides injure crops and weeds at low temperatures (Blair *et al.*, 1983; Edmund and York, 1987; Ferreira *et al.*, 1990; Gauvrit and Gaillardon, 1991; Malefyt and Quakenbush, 1991; Nalewaja *et al.*, 1990; Xie *et al.*, 1994), or crop and weed response to a particular herbicide is not affected by temperature (Smeda and Putnam, 1990; Snipes and Wills, 1994; Wichert *et al.*, 1992). The activity of postemergence herbicides, in general, is also greater at higher relative humidities than at lower humidity (Chase and Appleby, 1979; Coupland, 1983; Muzik, 1976; Nalewaja *et al.*, 1990; Ritter and Coble, 1981; Wichert *et al.*, 1992; Willingham and Graham, 1988; Wills, 1984).

As stated previously, the influence of weather on the performance of foliage-applied herbicides has received considerable attention. However, the effect of environmental factors on sulfonylurea herbicides performance is poorly documented. As with other herbicides, many factors, such as soil moisture, relative humidity, and air temperature, can influence the activity of sulfonylurea herbicides (Beyer *et al.*, 1988; Bruce *et al.*, 1996). Abnormally cool temperatures can produce crop injury by slowing the rate of sulfonylurea detoxification. It was found that for every 10°C decrease in air temperature, the rate of sulfonylurea herbicides detoxification drops by a factor of two to five (Beyer *et al.*, 1988). Conversely, high temperatures could increase crop injury by sulfonylurea herbicides (Eberlein and Miller, 1989; Swanton *et al.*, 1996). These two types of response, apparently in conflicting, are not necessarily be explained by the failure of the plant to detoxify of sulfonylureas. Factors such as spray retention, the rate of herbicide translocation, or herbicide compartmentalization in the plant may play a role in differential sensitivity of plants to sulfonylureas (Bruce *et al.*, 1996).

Some information is available regarding the effects of environmental factors on the performance of imidazolinone herbicides, which are ALS-inhibitors, like sulfonylureas. The activity of imidazolinones, such as imazaquin, imazethapyr, and imazapyr, is 15% to 50% greater in cool than in warm temperatures (Edmund and York, 1987; Malefyt and Quakenbush, 1991). The effect of temperature on imazamethabenz-methyl appears to be weed-species dependent (Pillmoor, 1985). On the other hand, significant cereal crop losses can occur because of improper timing of postemergence herbicide applications, as related to crop growth stage (Martin *et al.*, 1988 and 1989).

Corn injury caused by herbicides is unacceptable to growers. Corn tolerance to sulfonylurea herbicides can vary among locations (Doohan *et al.*, 1995) and years (Morton and Harvey, 1992; O'Sullivan *et al.*, 1995; Swanton *et al.*, 1996). Such variation has been related to environmental conditions on the date of herbicide application (Morton and Harvey, 1992; O'Sullivan *et al.*, 1995; Swanton *et al.*, 1996).

Rimsulfuron is a sulfonylurea herbicide commercialized for use in maize for the control of annual grasses and broad-leaf weeds, as well as for some troublesome perennial weed grasses[3,4]. Previous field experiments carried out in 1992 and 1993 on the Université Laval (Québec, Canada) showed that tolerance to rimsulfuron in maize varied between years (Fuentes, 1997). This difference in activity was suspected to be caused by variation in air temperature at the time of rimsulfuron treatment. Corn plants that were behind in their stage of growth at the date of rimsulfuron application were observed to be more sensitive than the average of the stand (4- to 5-leaf growth stage). No quantitative information, however, is available on the influence of environment on the tolerance of maize to rimsulfuron. In eastern Canada (Québec), maize may undergo temperature extremes as low as -0.6 C or as high as 34 C during the spraying season (Anonymous, 1982).

The objective of this study was to determine the response of six maize hybrids treated at two growth stages with different doses of rimsulfuron, and under various air temperature and relative humidity conditions. Such information will help interpret the selectivity of rimsulfuron in maize under field conditions. A better understanding of how the environment and maize growth stage at time of treatment influence rimsulfuron performance in maize could help growers optimize the use of rimsulfuron.

---

[3] Elim EP product label. DuPont Canada, Mississauga, Ontario, L5M 2J4.
[4] Ultim product label. DuPont Canada, Mississauga, Ontario, L5M 2J4.

MATERIALS AND METHODS

General

Glasshouse and growth chamber experiments were conducted at the Université Laval (Québec, Canada) to better understand the effect air temperature, relative humidity and growth stage at time of herbicide treatment, on maize hybrids response to rimsulfuron.

The maize hybrids in this research were selected from those hybrids tested under field conditions in 1992 and 1993 (Fuentes, 1997). The hybrids tested were adapted to three climatic zones of Québec: zone 1: > 2 700 CHU; zone 2: 2 500 to 2 700 CHU, and zone 3: 2 300 to 2 500 CHU. Two hybrids of each zone were evaluated in the current work. One of the two hybrids of each zone was more tolerant than the other (Fuentes, 1997). The maize hybrids studied were: (1) 'Cargill 2127' (tolerant) and 'Hyland HL 2272' (moderately tolerant) from zone 1; (2) 'Pickseed 2620' (tolerant) and 'Pionner 3897' (sensitive) from zone 2; (3) 'Hyland HL 2262' (moderately tolerant) and 'Pioneer 3979' (sensitive) from zone 3.

In all cases, maize hybrids were grown in a glasshouse in 12 cm-diameter plastic pots filled with a potting mixture consisting of peat moss, decomposed organic matter, sand, vermiculite, and perlite (2:2:2:1:1 by wt). Two maize kernels were planted 2 cm deep in each pot and thinned to one plant per pot one week after emergence.

Plants were watered twice a day and fertilized weekly with 50 ml of a water-soluble fertilizer solution (400 ppm N, 400 ppm P2O5, and 400 ppm K2O). Average glasshouse air temperature during the day was 22 C, and average night temperature was 19 C. Relative humidity ranged from 50% to 60%. Supplemental halide and fluorescent lighting was used to provide an illumination of *ca.* 380 μmol m^{-2} s^{-1} for a 14-h photoperiod.

In all experiments, rimsulfuron was applied at 20, 40, and 60 g a.i. ha^{-1} in a mixture with a non-ionic surfactant[5] at a concentration of 0.2% v/v. The rimsulfuron labeled dose in Canada is 15 g a.i ha^{-1}.[3] When this work was started in 1993, rimsulfuron was not registered in Canada. So, the recommended dosage in France of 20 g a.i ha^{-1} was used[6].

Each individual plant was an experimental unit, with five replicates (plants) of each treatment. Ten plants of each hybrid tested in every environmental condition or growth stage were included as an untreated control. Plant height and dry weight of each plant were measured 14 days after rimsulfuron treatment. Plant height was measured from the ground level to the tip of the youngest completely expanded leaf. Corn height and shoot dry weight were expressed as percentages of the height and shoot dry weight of the non-treated control hybrids of each environment or growth stage.

Air temperature and relative humidity interaction

Corn plants were grown in the glasshouse, as detailed above, until they reached the 4 -to 5-leaf growth stage. Rimsulfuron sprays were applied indoors using a laboratory CO_2-pressurized sprayer. A 8001 even flat-fan tip[7] was directed vertically downward and calibrated to deliver 400 L ha^{-1} at 207 kPa. Plants were placed 46 cm below the nozzle tip. The first and second leaves were positioned at right angles to the line of nozzle aspersion. Each plant was treated individually.

One day before rimsulfuron treatment, plants were selected for uniformity and placed in four different controlled environment chambers set at 14°C and 28°C with 60% or 75% RH. Thus, a growth chamber was assigned for each temperature and relative humidity combination.

Growth chambers were lit with fluorescent and incandescent lamps to provide *ca.* 400 μmol m^{-2} s^{-1} during a 14-h photoperiod. After herbicide application, the maize plants were transferred to the different growth chambers 10 to 15 min after treatment. Plants were maintained in the growth cabinets until final assessment.

The experiment was a split-plot design with a factorial arrangement of treatments. The whole plots (4) were the temperature and relative humidity combinations, and the sub-plots (18) were the six maize hybrids and the three rimsulfuron doses combinations. This four-factor experiment was conducted once.

Effect of air temperature conditions

Based on the results on previous experiment, a second experiment was carried out. Response of six maize hybrids to rimsulfuron was compared under: cool (14 C), moderate (21 C), and warm (28 C) temperature regimes in three separate growth chambers. The relative humidity in the three growth chambers was set at 75%.

Experimental procedure, maize hybrids, growing conditions, and maize growth stage at the time of treatment were the same as in previous experiment. However, the rimsulfuron spraying procedure differed from the preceding experiment. Plants were sprayed outdoors using a bicycle-mounted compressed air sprayer delivering 250 L ha^{-1} at 207 kPa. Plants receiving the same rimsulfuron dose were treated at the same time. After treatment, plants were transferred into the different growth cabinets set at 14, 21, or 28 C.

---

[5] AGRAL 90™; nonylphenoxypolyethoxy ethanol; Zeneca Agro, Longueil, Québec, J4G 1R9.
[6] Titus product label. DuPont de Nemours, Paris, France.
[7] Teejet 8001-E nozzle. Spraying Systems Co., North Avenue, Wheaton, IL 60287.

The experiment was a split-plot design with a factorial arrangement of treatments. The whole plots (3) were the temperature conditions and the sub-plots (18) were the combinations of the six maize hybrids and the three rimsulfuron doses. This experiment was run twice with five replicates for each treatment.

Maize growth stage

Performance of six maize hybrids treated at the 2- to 3-leaf and 4- to 5-leaf stages were compared to assess their rimsulfuron tolerance. Plants were grown under the same glasshouse conditions as indicated in the general procedure. The procedure for spraying rimsulfuron was the same followed in the second experiment. This experiment was a completely randomized design with a factorial arrangement of treatments (Factor A: growth stage, Factor B: hybrid, and Factor C: rimsulfuron dose). It was run twice with five replicates for each run.

Data analysis

Data for height and dry weight were expressed as percentages of the untreated control and subjected to factorial analysis of variance (ANOVA) using runs (blocks), temperature, relative humidity, hybrids, rimsulfuron dose, and growth stage as factors. Because weight and height variables in all three experiments were highly correlated (r = 0.85, 0.85 and 0.83 in experiments 1, 2 and 3, respectively), only weight data are reported. When appropriate, single degree of freedom contrasts were carried out.

RESULTS AND DISCUSSION

Air temperature and relative humidity interaction

The significant two-way and three-way interactions were temperature by dose and temperature by relative humidity by hybrid (Table 1). These interactions are examined in Figures 1 and 2, respectively.

Partitioning the temperature by dose interaction into single degree of freedom contrasts revealed both a significant linear and quadratic response to the dose (Table 1). When averaged across hybrids and relative humidity levels, maize injury varied slightly among herbicide doses (16% to 20% DWR) under the cool temperature regime (14 C). At 28 C, maize injury was 43% at both 20 and 40 g a.i. and 63% at 60 g a.i.

The temperature by relative humidity by hybrid interaction is examined in Figure 1. Increasing the relative humidity level from 60% to 75% did not increase rimsulfuron injury in any of the hybrids grown at 14 C. Corn weight reduction was never more than 30% at 14 C, whereas maize injury at 28 C was considerably greater for the majority of hybrids. At 28 C and 60% RH, maize weight reduction was greater than 30%, except for Pickseed 2620 (28% DWR).

Table 1. F-statistics and error mean squares for analysis of shoot dry weight reduction of maize hybrids treated with rimsulfuron under various air temperature and relative humidity conditions.

Source of variation	df	F-statistic
Temperature (T)	1	155.08 *
Relative humidity (RH)	1	0.2690
Error mean square (a)	1	*538.41*
T x RH	1	1.67
Hybrid (Hyb)	5	7.99 **
T x Hyb	5	3.94 **
Hyb x RH	5	7.97 **
T x Hyb x RH	5	8.32 **
Dose	2	14.59 **
T x Dose	2	9.61 **
T x Dose linear	1	11.72 **
T x Dose quadratic	1	7.49 **
Dose x RH	2	1.85
T x Dose x RH	2	0.76
Dose x Hyb	10	1.23
T x Dose x Hyb	10	1.05
Dose x Hyb x RH	10	0.33
T x Dose x Hyb x RH	10	1.09
Error mean square (b)	288	*323.14*
Total	359	

When the relative humidity level was increased from 60% to 75%, maize injury increased dramatically, especially in Pioneer 3897, Hyland HL 2262, and Pioneer 3979 (70% DWR). Injury to hybrids of zone 1 (Cargill 2127 and Hyland HL 2272) growing at 28C was lower, around 42% at both 60% and 75% relative humidity (Figure 1). On average, hybrids from zone 1 were more tolerant (29% DWR) than hybrids of both zones 2 and 3 (37% DWR for both zones together). In spite of the significant temperature by relative humidity by genotype interactions noted, in the present study, warm temperatures maximized rimsulfuron activity in maize.

Environmental conditions at the time of postemergence herbicide application can have substantial influence on herbicide activity. Higher air temperature and higher relative humidity at the time of postemergence herbicide treatment have been reported to increase the activity of foliar-applied herbicides. Increased activity under warm conditions has been reported for a variety of herbicides, e.g. fluazyfop-butyl (Kells *et al.*, 1984), difenzoquat (Miller *et al.*, 1984), acifluorfen (Wills and McWhorter, 1981), pyrazon (Koren and Ashton, 1973), sethoxydim (Wills, 1984) and glyphosate (Coupland, 1983).

The greater activity of rimsulfuron at 75% RH, as compared to that at 60%, is not surprising. It is well established that a number of non-polar and weak acid

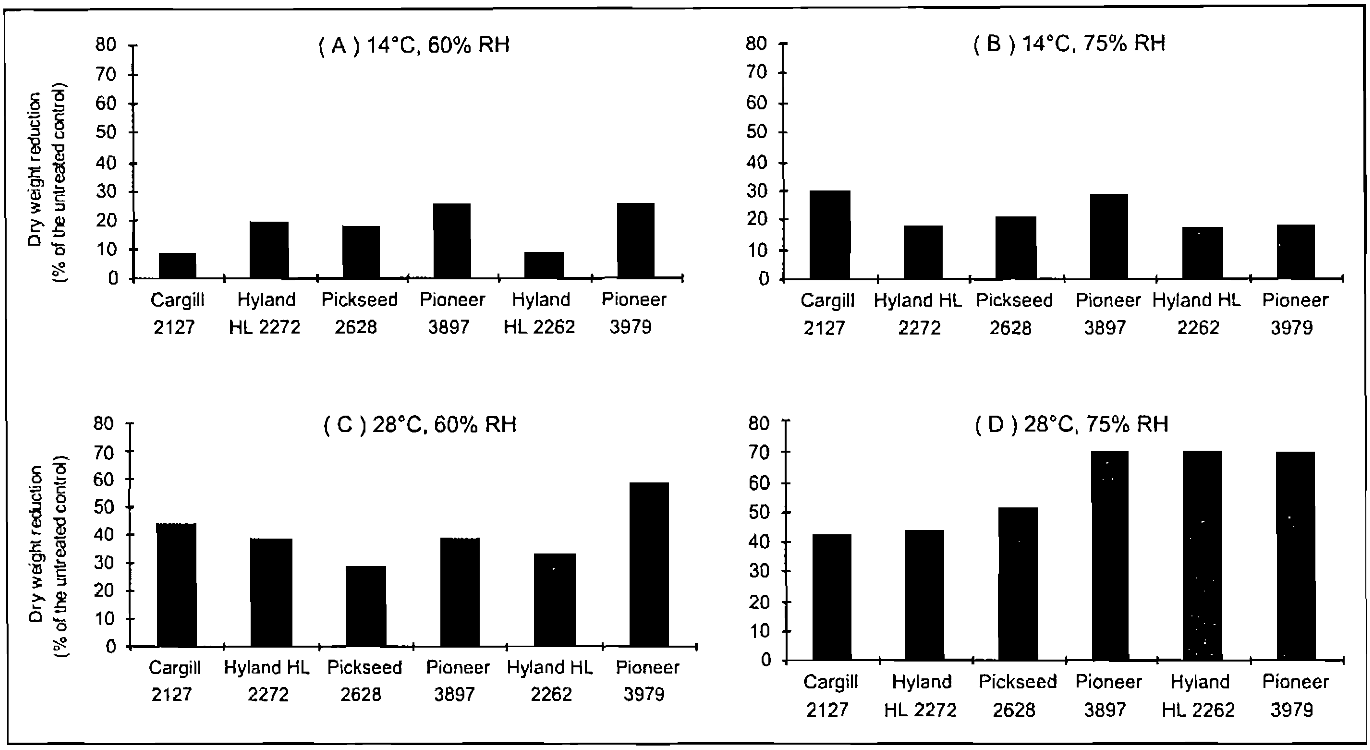

Figure 1. Effect of two air temperatures and two relative humidity levels on shoot dry weight reduction of maize hybrids treated with rimsulfuron at 15 DAT. Each data point is the mean of 15 observations (3 doses and 5 replicates). S`y = 8.04.

herbicides are less active at low RH levels than at high RH (Willingham and Graham, 1988). At least, part of this difference in activity is ascribed to differences in herbicide uptake, which has been reported to be reduced as RH decreases (Ritter and Coble, 1981; Wills and McWhorter, 1981). This may be due to a number of factors, such as delay in evaporation of the droplet, promotion of stomatal opening, and hydratation of the cuticle (Chase and Appleby, 1979). On the other hand, reduced foliar absorption in an environment of low relative humidity has been attributed to crystallization of the herbicide on the leaf surface (Kloppenburg and Hall, 1990; Sharma *et al.*, 1971).

Effect of air temperature conditions

The results from previous experiment showed that temperature regimes and rimsulfuron doses seemed to be the most important factors explaining maize response to this herbicide. Thus, a second experiment was designed to further study the effects of three temperature regimes, cool (14 C), medium (21 C), and warm (28 C), on the tolerance of maize hybrids to rimsulfuron. As in the prior experiment, the main effects of temperature, hybrid and dose were significant, as well as the temperature by dose, hybrid by temperature, and temperature by hybrid by dose interactions (Table 2). The hybrid by dose interaction was not significant (Table 2).

The interaction between temperature and dose was examined by means of single degree of freedom contrasts (Table 2). The contrast testing the linear by linear response was significant, while the linear by quadratic

Table 2. F-statistics and error mean squares for analysis of shoot dry weight reduction of maize hybrids treated with rimsulfuron under various air temperature conditions.

Source of variation	df	F-statistic
Block (B)	1	1.45
Temperature (T)	2	133.92 **
Error mean square (a)	2	*508.69*
Hybrid (Hyb)	5	36.94 **
Dose	2	18.24 **
Hyb x Dose	10	0.76
Hyb x T	10	9.68 **
T x Dose	4	6.81 **
T linear x Dose linear	1	21.89 *
T quadratic x Dose linear	1	0.95
T linear x Dose quadratic	1	1.23
T quadratic x Dose quadratic	1	3.15
Hyb x T x Dose	20	2.29 **
Error mean square (b)	483	*218.63*
Total	539	

* ** F-statistic significant at 0.05 or 0.01 level, respectively

and quadratic by quadratic combinations were not significant (Table 2). This indicates that injury increases linearly with an increase in dose at every temperature; likewise, at each dose, increasing temperature caused a linear increase in injury (Figure 2). At 14 C, dry weight reduction did not exceed 13%, measured over all rimsulfuron doses tested. Increasing the temperature from 14 C to 21C increased damage to 26% (DWR) at both 20 and 40 g a.i. rimsulfuron doses, and to 33% DWR at 60 g a.i. At 28°C, DWR ranged from 40% to 58% (Figure 2).

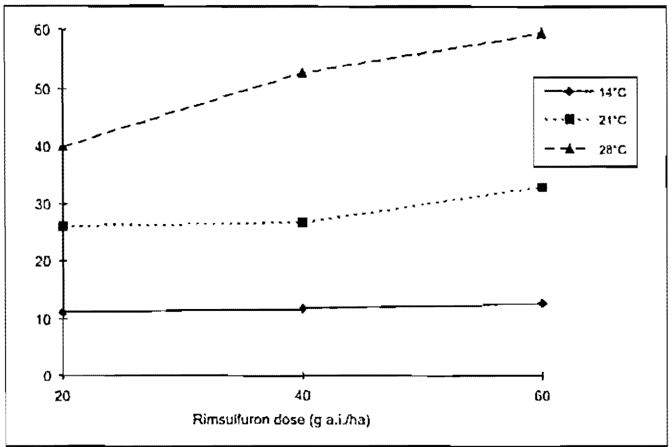

Figure 2. Effect of three air temperatures on shoot dry weight reduction of maize hybrids treated with rimsulfuron at 20, 40 and 60 g a.i. ha-1, 15 DAT. Each data point is the mean of 60 observations (6 maize hybrids and 10 replicates). S`y = 2.29.

The temperature by hybrid by dose interaction is examined in Figure 3. In all hybrids, dry weight reduction was never over 25% under cool conditions, even at 3 times the labeled dose for France. At 21C, Cargill 2127, Hyland HL 2272, and Pickseed 2620 were not greatly affected by rimsulfuron at 60 g a.i. ha-1 (DWR <25%). Hyland HL 2262 tolerated up to twice the labeled dose (DWR of 25%) (Figure 3).

The highest level of damage was registered at the warmer temperature (28 C), at which only Cargill 2127 and Pickseed 2620 did not exceed 30% injury when treated at the labeled dose. Cargill 2127 appears to be the most tolerant hybrid, since dry weight reduction was less than 40%, even at the 60 g a.i. ha-1 rimsulfuron treatment. Injury to the other hybrids varied from 35% to 60% at the 20 g a.i. ha-1 dose, and from 54% to 75% at 60 g a.i. ha-1 (Figure 3). As in the previous experiment, hybrids of zone 1 were more tolerant (23% DWR) than hybrids of zone 2 and 3 (32% and 37% DWR, respectively).

Temperature has been reported to affect herbicide absorption and translocation (Price 1983; Wanamarta and Penner 1989). Uptake and translocation of foliar-applied herbicides increase at both high temperature and high relative humidity (Wills, 1984; Wills and McWhorter, 1981). On the other hand, higher activity of various postemergence herbicides has also been reported to occur at lower temperatures. This is the case of chlorsulfuron (Ferreira *et al.*, 1990) and barban (Miller *et al.*, 1978) in wheat. Imazamethabenz also has been reported to injure crop species in cool environments (Malefyt and Quakenbush, 1991; Xie *et al.*, 1994). Greater activity of imidazolinone herbicides in both crops and weeds has been explained by a slower rate of herbicide detoxification (Malefyt and Quakenbush, 1991). In the present study, the lower activity of rimsulfuron under the cool condition needs more explanation. Factors such as foliar absorption, translocation, or retention may play a role in herbicide tolerance (Bruce *et al.*, 1996).

Corn growth stage

A third experiment was conducted to determine the effect of maize growth stage at time of rimsulfuron treat-

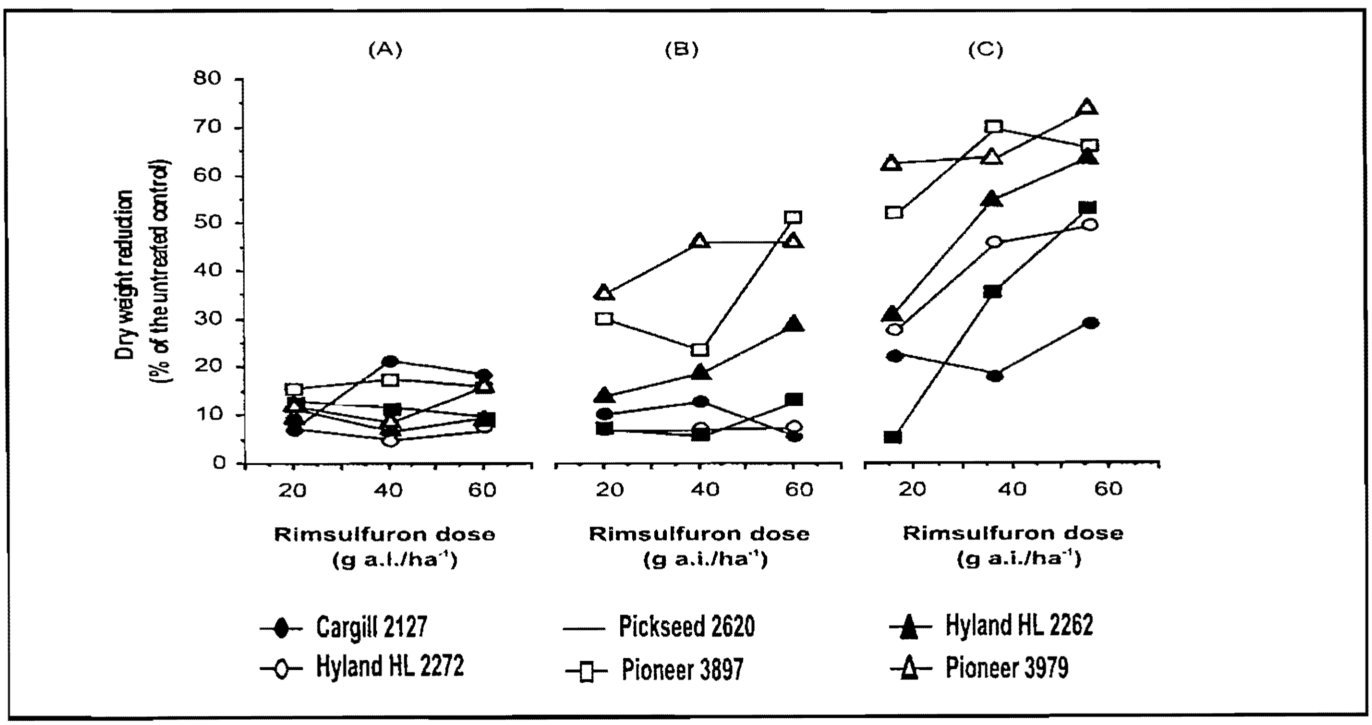

Figure 3. Percentage of shoot dry weight reduction in six maize hybrids as affected by rimsulfuron applied at 20, 40 and 60 g a.i. ha^{-1}, 15 DAT. Rimsulfuron was applied to plants grown at (A) 14 C, (B) 21 C, and (C) 28 C. Each data point is the mean of 30 observations (3 rimsulfuron doses and 10 replicates). S y = 4.67.

Table 3. F-statistics and error mean squares for analysis of shoot dry weight reduction of maize hybrids treated with rimsulfuron at two growth stages.

Source of variation	df	F-statistic
Block (B)	1	977.16 *
Growth stage (GS)	1	610.11 *
Error mean square (a)	1	*19.69*
Hybride (Hyb)	5	74.89 **
Dose	2	7.10 **
Dose linear	1	14.10 **
Dose quadratic	1	0.09
Hyb x Dose	10	0.76
GS x Hyb	10	3.27 **
GS x Dose	2	0.00
GS x Hyb x Dose	10	0.49
Error mean square (b)	322	*97846.65*
Total	359	

* ** F-statistic significant at 0.05 or 0.01 level, respectively

ment. Corn hybrids were treated at the 2- to -3 and 4- to 5-leaf stages with increasing rimsulfuron doses (20, 40, and 60 g a.i. ha1). The main effect of all factors (growth stage, dose and hybrid) and the hybrid by growth stage interaction were significant (Table 3).

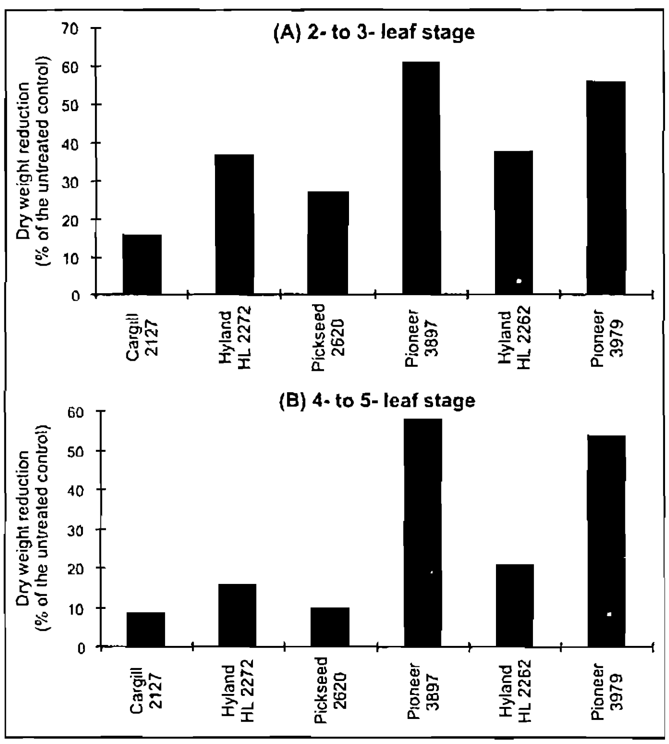

Figure 4. Effect of growth stage, (A) 2- to 3-leaf stage and (B) 4- to-5 leaf stage, at time of rimsulfuron treatment on shoot dry weight reduction in six maize hybrids at 15 DAT. Data are means.

The growth stage by hybrid interaction is presented in Figure 4. Cargill 2127 and Pickseed 2620 were injured less than 30% after being treated with rimsulfuron at the 2- to 3-leaf growth stage. In contrast, DWR of the remaining hybrids varied between 37% and 61%. Tolerance of Cargill 2127, Pickseed 2620, Hyland HL 2272 and Hyland HL 2262 to rimsulfuron increased when treated at the 4- to 5-leaf growth stage, and average DWR was less than 20%. Pioneer 3897 and Pioneer 3979 were the most susceptible hybrids. Phytotoxicity of these hybrids was greater than 50% at both growth stages (Figure 4). As in prior experiments, hybrids from zone 1 were more tolerant than those from the other two zones. Average DWR of hybrids from zone 1 was 19.0%, whereas DWR of the hybrids from zones 2 and 3 averaged 39% and 44%, respectively.

With regard to the main effect of the dose, the response of maize hybrids to increasing doses of rimsulfuron was linear (Table 4). Dry weight reduction averaged over all hybrids and growth stages was 27.0 %, 33.0%, and 38.0% at 20, 40, and 60 g a.i. ha^{-1}, respectively.

Applications of rimsulfuron or of the 1:1 rimsulfuron plus nicosulfuron premix are recommended in maize from 1- to 3 or 1- to 6-leaf growth stage of maize, respectively (Anonymous, 1996). The data from our study showed that maize hybrids were, on average, more sensitive to rimsulfuron at an early development stage. Likewise, it has been reported that young potato plants were more sensitive to rimsulfuron than older ones (Reinke *et al.*, 1991).

With regards to nicosulfuron, a herbicide closely related to rimsulfuron, is recommended for use in maize at the 4- to 8-leaf growth stage (Beraud and Delahousse, 1993). Corn grain yield, however, was 12% to 8 % lower when nicosulfuron was applied at the 7-leaf stage, instead of at the 3- or 5-leaf stage, respectively (Robinson *et al.*, 1993). Nevertheless, this reduction would be related more to the duration of weed competition than to herbicidal phytotoxicity (Robinson *et al.*, 1993).

In fact, it is imperative to prevent weed competition in maize after the 4- to 5-leaf stage in order to avoid yield reduction (Robinson *et al.*, 1993). Swanton *et al.*, (1996) reported maize yield losses when DPX-79406 (nicosulfuron:rimsulfuron, 1:1 premix) was applied late postemergence at the 6- to 9-leaf stage, compared to early application at the 3- to 6-leaf stage. Yield losses when DPX-79406 was applied late postemergence may have been caused either by crop injury from the herbicide or by weed interference from early emerging weeds. On the other hand, Carey and Kells (1995) found that nicosulfuron plus bromoxynil injured maize plants more severely at the 2- to 3-leaf stage compared with plants treated at the 5- to 6-leaf stage. This finding agrees with the results of our study. Thus, maize hybrids were generally, more sensitive to rimsulfuron when applied at the 2- to 3-leaf stage, in comparison to applications at the 4- to 5-leaf stage.

Results of the three experiments showed similar trends with regard to hybrid tolerance to rimsulfuron. In general, Cargill 2127 and Pickseed 2620 appeared to be the most tolerant hybrids, while Pioneer 3897 and Pioneer 3976 were the most sensitive. Hyland HL 2272 and Hyland HL 2262 showed an intermediate response. However, the temperature regime can modify the activity of rimsulfuron in maize hybrids. The influence of temperature has been attributed to a greater absorption and translocation of rimsulfuron at warm temperatures (Fuentes, 1997). The results obtained emphasize the importance of considering all aspects of the performance of a herbicide when investigating the underlying causes for changes in biological activity.

Mekki and Leroux (1994) calculated the rimsulfuron doses needed to cause 90% dry biomass reduction (GR_{90}). Wild oats (*Avena fatua* L.), smooth crabgrass (*Digitaria ischaemum* (Schreb. ex Schweig) Schreb. ex Mühl.), and common ragweed (*Ambrosia artemisiifolia* L.) required ≥ 26 g a.i. ha^{-1}, and proso millet (*Panicum milliaceum* L.), green foxtail (*Setaria viridis* (L.) Beauv.) and giant foxtail (*Setaria faberii* Herrm.), required 13 g a.i. ha^{-1} or less to cause a biomass weight reduction of 90%. The recommended dose of rimsulfuron in Canada is 15 g a.i. ha^{-1} (Anonymous, 1996).

Based on the results of the current work, adjustment of the rimsulfuron dose is suggested, depending on maize cultivar, maize growth stage, weed species and temperature. For example, when troublesome weeds like wild oats, smooth crabgrass, or common ragweed are present, a dose of 30 g a.i. ha^{-1} could be used with a tolerant cultivar like Cargill 2127 or Pickseed 2620, regardless of temperature at time of treatment.

The label dose (15 g a.i. ha^{-1}) could be used if sensitive weed species are predominant, as well as when less tolerant maize cultivars are grown. In this case, early postemergence treatments should be avoided. In a like manner, if temperature at the time of application is greater than 21 C, rimsulfuron treatment should be avoided when susceptible hybrids are grown.

ACKNOWLEDGMENTS

The authors thank Dr. Alain Olivier and Dr. Jean Collin (Université Laval, Département de Phytologie, Québec Canada) for their review and useful comments on the manuscript. Thanks are also due to Mr. Peter Monagham for his help in correcting the English.

LITERATURE CITED

GUIDE DE LUTTE contre les mauvaises herbes. Ontario. Ministère de l'Agriculture, de l'Alimentation et des Affaires Rurales. Publication 1996. 75F.

CANADIAN CLIMATE normals / Normales climatiques au Canada. Temperature /Température. 1951 to 1982. Vol. 2. Environment Canada. Atmospheric Environment Service. The Canadian Climate Program. 1982.

BERAUD, J. M. and B. DELAHOUSSE. 1993. Le nicosulfuron: herbicide de postlevée sélectif du maïs. Phytoma: La Défense deS Végétaux 446:57-60.

BEYER, E. M. Jr., M. J. DUFFY, J. V. HAY and D. D. SCHLUETER. 1988. Sulfonylureas. In P. C. Kearney and D. D. Kaufman, eds. Herbicides Chemistry, Degradation and Mode of Action. Vol. 3. New York: Marcell Dekker Inc. p. 117-189.

BLAIR, A. M., W. G. RICHARDSON and T. M. WEST. 1983.The influence of climatic factors on metoxuron activity on *Bromus sterilis* L. Weed Research 23:259-265.

BRUCE J. A., J. B. CAREY, D. PENNER and J. J. KELLS. 1996. Effect of growth stage and environment on foliar absorption, translocation, metabolism and activity of nicosulfuron in Quackgrass (*Elytrigia repens*). Weed Science 44: 447-454.

CAREY, J. B. and J. J. KELLS. 1995.Timing of total postemergence herbicide applications to maximize weed control and maize (*Zea mays*) yield. Weed Technol. 9:356-361.

CHASE, R. L. and A. P. APPLEBY. 1979.Effects of humidity and moisture stress on glyphosate control of *Cyperus rotundus* L. Weed Research 19:241-246.

COUPLAND, D. 1983. Influence of light, temperature, and humidity on the translocation and activity of glyphosate in Elymus repens (= *Agropyron repens*). Weed Research 23:347-355.

COUPLAND, D. 1989. Pre-treatment environmental effects on the uptake, translocation, metabolism and performance of fluazifop-butyl in *Elymus repens*. Weed Research 29:289-297.

DOOHAN, D. J., J. A. IVANY and K. V. MCCULLY. 1995. Tolerance of early maturing maize hybrids to nicosulfuron/rimsulfuron 1:1 premix. Weed Science Soc. Am. Abs. 35: 7.

EBERLEIN, C. V. and T. L. MILLER. 1989. Corn (*Zea mays*) tolerance and weed control with thiameturon. Weed Technoogy 3:255-260.

EDMUND, R. M. and A. C. YORK. 1987. Effects of rainfall and temperature on postemergence control of sicklepod (*Cassia obtusifolia*) with imazaquin and DPX-F6025. Weed Science 35:231-236.

EVERAERER, L. 1990. Le DPX-E9636: Herbicide maïs. Phytoma. La défense des Végetaux 433:65-67.

FAWCETT, J. A., R. G. HARVEY, W. E. ARNOLD, T. T. BAUMAN, C. V. EBERLEIN. J. J. KELLS, L. J. MOSHIER, F. W. SLIFE and R. G. WILSON. 1987. Influence of environment on maize (*Zea mays*) tolerance to setoxydim. Weed Science 35: 568-575.

FERREIRA, K. L., T. K. BAKER and T. F. PEEPER. 1990. Factors influencing winter wheat (*Triticum aestivum*) injury from sulfonylurea herbicides. Weed Technology 4:724-730.

FUENTES, C. L. 1997. Mécanisme de sélectivité et hérédité de la tolérance au rimsulfuron chez le maïs (*Zea mays* L.). Ph. D. Dissertation. Université Laval, Faculté des Sciences de l'Agriculture et de l'Alimentation, Département de Phytologie, Québec, Canada.

GAUVRIT, C. and P. GAILLARDON. 1991. Effect of low temperatures on 2,4-D behaviour in maize plants. Weed Research 31:135-142.

KAPUSTA, G., R. F. KRAUSZ, M. KHANAND and J. L. MATTHEWS. 1994. Effect of nicosulfuron rate, adjuvant and weed size on annual weed control in maize (*Zea mays*). Weed Technology 8: 696-702.

HAMMERTON, J. L. 1967. Environmental factors and susceptibility to herbicides. Weeds 15:330-336.

KELLS, J. J., W. F. MEGGITT and D. PENNER. 1984. Absorption, translocation and activity of fluazifop-butyl as influenced by plant growth stage and environment. Weed Science 32:143-149.

KLOPPENBURG, D. J. and J. C. HALL. 1990. Effect of formulation and environment on absorption and translocation of clopyralid in *Cirsium arvense* (L.) Scop. and *Polygonum convolvulus* L. Weed Research 30:9-20.

KOREN, E. and F. M. ASHTON. 1973. Influence of temperature on absorption, translocation and metabolism of pyrazon in sugar beet. Weed Science 21:241-245.

MARTIN, D. A., S. D. MILLER and H. P. ALLEY. 1988. Barley (*Hordeum vugare*) response to herbicides applied a three growth stages. Weed Technology 2:41-45.

MARTIN, D. A., S. D. MILLER and H. P. ALLEY. 1989. Winter wheat (*Triticum aestivum*) response to herbicides applied at three growth stages. Weed Technology 3:90-94.

MALEFYT, T. and L. QUAKENBUSH. 1991. Influence of environmental factors on the biological activity of the imidazolinone herbicides. *In* D. L. Shaner and S. L. O'Connor, eds. The imidazolinone herbicides. Boca Raton, FL: CRC Press. pp. 103-128.

MEKKI, M. and G. D. LEROUX. 1994. Activity of nicosulfuron, rimsulfuron and their mixture on field maize (*Zea mays*), soybean (*Glycine max*) and seven weed species. Weed Technology 8:436-440.

MILLER, S. F., J. D. NALEWAJA and A. DOBRANSKI. 1984. Temperature effect on difenzoquat phytotoxicity. Weed Science 32:150-153.

MILLER, S. F., J. D. NALEWAJA, A. DOBRANSKI and J. PUDELKO. 1978. Temperature effect on barban phytotoxicity. Weed Science 26:132-134.

MORTON, C. A. and R. G. HARVEY. 1992. Sweet maize (*Zea mays*) hybrids tolerance to nicosulfuron. Weed Technology 6:91-96.

MORTON, C. A. and R. G. HARVEY. 1994. Simulated environments influence primisulfuron efficacy. Weed Science 42:424-429.

MUZIK, T. J. 1976. Influence of environmental factors on toxicity to plants. *In* L. J. Audus, ed. Herbicides Physiology, Biochemistry and Ecology. Vol 1. London: Academic Press. pp. 203-247.

NALEWAJA, J. D., J. PALCZYNSKI and F. A. MANTHEY. 1990. Imazethapyr efficacy with adjuvants and environments. Weed Technology 4:765-770.

NALEWAJA, J. D., J. PUDLELKO and K. A. ADAMCZEWSKI. 1975. Influence of climate and additives on bentazon. Weed Science 23:504-507.

O'SULLIVAN, J., R. A. BRAMMALL and W. J. BOUW. 1995. Response of sweet maize (*Zea mays*) cultivars to nicosulfuron plus rimsulfuron. Weed Technology 9:58-62.

PILLMOOR, J. B. 1985. Influence of temperature on the activity of AC 222,293 against *Avena fatua* L. and *Alopecurus myosuroides* Huds. Weed Research 25:433-442.

PRICE, C. E. 1983. The effect of environment on foliage uptake and translocation of herbicides. Aspects Appl. Biol. 4:157-169.

REINKE, H., A. ROSENZWEIG, J. CLAUS, M. KREIDI, C. CHISHOLM and P. JENSEN. 1991. DPX-E9636. Experimental sulfonylurea herbicide for potatoes. Proc. Br. Crop Protec. Conference 1, 445-451.

RITTER, R. L. and H. D. COBLE. 1981. Influence of temperature and relative humidity on the activity of acifluorfen. Weed Science 29:480-485.

ROBINSON, D. K., D. W. MONKS, J. R. SCHULTHEIS and A. D. WORSHAM. 1993. Sweet maize (*Zea mays*) cultivar tolerance to application timing of nicosulfuron. Weed Technology 7:840-843.

SHARMA, M. P., F. Y. CHANG and W. H. VANDEN BORN. 1971. Penetration and translocation of picloram in Canada thistle. Weed Science 19:349-354.

SMEDA, R. J. and A. R. PUTNAM. 1990. Influence of temperature, rainfall, grass species, and growth stage on efficacy of fluazifop. Weed Technology 4:349-355.

SNIPES, C. E. and G. D. WILLS. 1994. Influence of temperature and adjuvants on thidiazuron activity in cotton leaves. Weed Science 42:13-17.

SWANTON, C. J., K. CHANDLER, M. J. ELMES, S. D. MURPHY and G. W. ANDERSON. 1996. Postemergence control of annual grasses and maize (*Zea mays*) tolerance using DPX-79406. Weed Technology 10: 288-294.

WANAMARTA, G. and D. PENNER. 1989. Foliar absorption of herbicides. Rev. Weed Science 4:215-231.

WICHERT, R. A., R. BOZSA, R. E. TALBERT and L. R. OLIVER. 1992. Temperature and relative humidity effects on diphenylether herbicides. Weed Technology 6:19-24.

WILLINGHAM, G. L. and L. L. GRAHAM. 1988. Influence of environmental factors and adjuvants on the foliar penetration of acifluorfen in velvetleaf (*Abutilon theophasti*): An analysis using the fractional factorial design. Weed Science 36:824-829.

WILLS, G. L. 1984. Toxicity and translocation of sethoxydim in Bermudagrass (*Cynodon dactylon*) as affected by environment. Weed Science 32:20-24.

WILLS, G. L. and C. G. MCWHORTER. 1981. Effect of environment on the translocation and toxicity of acifluorfen to showy crotalaria (*Crotalaria spectabilis*). Weed Science 29:397-401.

XIE, H. S., W. A. QUICK and A. I. HSIAO. 1994. Spring cereal response to imazamethabenz and fenoxa-prop-p-ethyl as influenced by environment. Weed Technology 8:713-716.