TOLERANCE OF FIELD MAIZE HYBRIDS TO RIMSULFURON

Tolerancia de híbridos de maíz al rimsulfuron

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SUMMARY

The response of eighteen maize (*Zea mays* L.) hybrids to rimsulfuron [(1-(4-6-dimetoxipyrimidin-2-yl))-3-((ethylsulfonyl)-2-pyridylsulfonyl) urea] was evaluated under field conditions on the campus of Université Laval (Québec, Canada). These hybrids were selected based on a wide range of maize heat unit (MHU) requirements. The response of hybrids to postemergence treatment of rimsulfuron (20, 40, and 60 g a.i. ha^{-1}) was compared to an untreated hand-weeded control. The data recorded included visual shoot phytotoxicity, plant height, and above-ground dry matter.

Visual phytotoxicity varied among the same hybrid with respect to the date of evaluation, from 32% to 46% in 1992, and from 11% and 23% in 1993. According to Principal Component Analysis (PCA), the first component accounted for 82% of the total variance, with high weights ('eigenvectors') on the visual phytotoxicity 14, 21, 28, and 35 DAT. This signified that comparision among hybrids for sensitivity to rimsulfuron could be carried out by means of visual scores 14, 21, 28 or 35 DAT. Hybrids react differently to different doses of rimsulfuron. Some hybrids tolerated a high dose of rimsulfuron, while others were severely injured at a low dose.

A hybrid phytotoxicity score (HPS), based on the mean of visual scores at 14, 21, 28 and 35 DAT, averaged across all three application doses, was used to group the hybrids into three categories according to their degree of tolerance:

I. Tolerant (HPS < 0); II. Moderately tolerant (HPS $\cong$ 0); and III. Sensitive (HPS > 0).

Tolerance to rimsulfuron varied also depending on genotypes which was positively correlated to MHU requirements. Hybrids of zone 1 of Québec ($>$ 2700 MHU) were more tolerant (based on the HPS) than hybrids of zone 2 (2500 to 2700 MHU) and zone 3 (2300 to 2500 MHU).

Key words: herbicide tolerance, phytotoxicity score, sulfonylureas, maize heat units, multivariate analysis.

RESUMEN

La respuesta de 18 híbridos de maíz al herbicida rimsulfuron fue evaluada bajo condiciones de campo en las instalaciones de la Universidad Laval (Québec, Canadá). Estos híbridos se seleccionaron con base en sus requerimientos de Unidades Térmicas Maíz (UTM). La respuesta de estos materiales a la aplicación posemergente del rimsulfuron en dosis de 20, 40 y 60 g i.a. ha^{-1}) se comparó con un testigo desyerbado manualmente. Las variables que se evaluaron incluyeron la fitotoxicidad visual, la altura de planta y la materia seca de parte aérea.

La fitotoxicidad visual varió para el mismo híbrido, respecto a la fecha de evaluación, del 32% al 46% en 1992, y de 11% al 23% en 1993. De acuerdo con el Análisis de Componentes Principales (ACP), el primer componente aportó el 82% del total de la varianza y con alto peso ("eigenvectors") de la variable fitotoxicidad visual tomada a los 14, 21, 28 y 35 días después del tratamiento (DDT). Esto significa que las comparaciones entre híbridos para estimar la sensibilidad al rimsulfuron puede realizarse mediante la evaluación visual del daño 14, 21, 28 o 35 DDT. Los híbridos respondieron de manera diferente al rimsulfuron aplicado en distintas dosis. Algunos híbridos toleran altas dosis del herbicida, mientras que otros fueron severamente afectados a bajas dosis del compuesto.

Se propuso un Indice de Fitotoxicidad (IF) basado en la evaluación visual del daño a los 14, 21, 28 y 35 DDT considerando las tres dosis de aplicación del compuesto, con el fin de agrupar los materiales de maíz en tres categorías, según su grado de tolerancia: I. Tolerante (IF < 0); II. Moderadamente Tolerante (IF $\cong$ 0); y III. Sensible (HPS > 0).

La tolerancia al rimsulfuron varió también dependiendo del genotipo, y este grado de tolerancia estuvo positivamente correlacionado con los requerimientos en UTM. Los híbridos de la zona 1 de Québec ($>$2 700 UTM) fueron más tolerantes (con base en el IF) que los híbridos de la zona 2 (2 500 a 2 700UTM) y de la zona 3 (2 300 a 2 500 UTM).

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Palabras clave: tolerancia a herbicidas, índice de fitotoxicidad, sulfonylureas, unidades térmicas maíz, análisis multivariado.

INTRODUCTION

Maize is the main cash crop of Québec, Canada, with about 300 000 ha harvested every year (Belzile & Provençal, 1994). The use of postemergence sulfonylurea herbicides allows maize growers to apply herbicides when weed populations exceed bioeconomic thresholds (Oliver, 1988), thus avoiding dependence on preemergence herbicides that are applied to the soil as insurance treatments.

Sulfonylureas are an innovation in herbicides because they are used at low doses (2 to 20 g a.i ha^{-1}) and act on a biochemical target, the enzyme ALS (acetolactate synthase or acetohydroxyacid synthase) (Chaleff & Mauvais, 1984; Ray, 1985). It is the key enzyme in the branched chain amino acids that produces leucine, isoleucine, and valine (Beyer *et al.*, 1988; Stidhman, 1991). ALS is present in plants and micro-organisms but not in mammals (Matsunaka *et al.*, 1985). This feature, combined with the low toxicity and with the very low application doses of the sulfonylureas, makes them attractive from environmental and human health standpoints (Beyer *et al.*, 1988).

The availability of selective, highly active, postemergence sulfonylurea herbicides for maize may represent a viable alternative to triazine herbicides. Rimsulfuron (DPX E-9636), [(1-(4-6-dimetoxipyrimidin-2-yl))-3-ethylsulfonyl) urea], is a novel postemergence herbicide. It offers maize growers a new alternative for the control of noxious perennial and annual grass weeds such as *Sorghum halepense*, *Elytrigia repens*, *Setaria* spp., *Cenchrus* spp., *Digitaria* spp., *Panicum* spp., and annual *Sorghum* species (Palm *et al.*, 1989; Everaerer, 1991). A wide range of broad-leaved weeds, including species that have become resistant to triazines, also show sensitivity to rimsulfuron (Palm *et al.*, 1989).

Rimsulfuron has many favourable characteristics, including rapid degradation in soil, insignificant ground and surface water contamination, and low mammalian toxicity (Palm *et al.*, 1989; Everaerer, 1991; Reinke *et al.*, 1991; Vicari *et al.*, 1996). Rimsulfuron degrades rapidly in the soil, predominantly via chemical pathways (Schneiders *et al.*, 1993; Onofri, 1996; Vicari *et al.*, 1996). Microbial degradation plays only a minor role (Schneiders *et al.*, 1993; Onofri, 1996). The half-life in soil varies between 5.7 days (field) and 24.5 days (laboratory) (Schneiders *et al.*, 1993). A faster degradation rate was observed in acidic conditions, as compared to that at neutral and alkaline pH values (Schneiders *et al.*, 1993; Vicari *et al.*, 1996). For instance, Vicari *et al.* (1996) reported that rimsulfuron's half-life at pH 4 ranged from 0.16 to 5.8 days. These studies indicate that rimsulfuron has a short persistance in soil. Therefore, no restrictions are expected for crops grown in a normal rotation following applications of rimsulfuron (Palm *et al.*, 1989; Everaerer, 1991; Schneiders *et al.*, 1993; Onofri, 1996).

Rimsulfuron was commercialized in France for use in maize under the trade name TITUS™ (DuPont de Nemours, Paris, France; Everaerer, 1991). In eastern Canada, rimsulfuron has been registered under the trade name ELIM EP™ (DuPont Canada Inc., Mississauga, Ontario, L5M 2J4) (Anonymous, 1996), and also as a nicosulfuron:rimsulfuron 1:1 premix (ULTIM™, DuPont Canada Inc., Mississauga, Ontario, L5M 2J4), formerly DPX-79406 (Anonymous, 1996). This last mixture reduces potential injury to crop in rotations and improves rimsulfuron selectivity in maize, compared to the full rate of rimsulfuron (Mekki, 1994). Rimsulfuron is also recommended for use in potato (Leep *et al.*, 1991; Reinke *et al.*, 1991; Eberlein *et al.*, 1994; Ackley *et al.*, 1996) and other Solanaceous crops (Reinke *et al.*, 1991; Bewick *et al.*, 1995). However, application of rimsulfuron or related sulfonylureas to maize treated with organophosphate insecticides can cause crop injury (Beyer *et al.*, 1988; Everearer, 1991; Bailey & Kapusta, 1994; Ackley *et al.*, 1996).

Maize sensitivity to rimsulfuron depends on the cultivar (Green and Ulrich, 1994; Doohan *et al.*, 1995; McMullan & Blackshaw, 1995). Also, Bulcke & Callens (1996) classified maize as a moderately sensitive species, based on the degree of inhibition at the root level when rimsulfuron was pre-plant incorporated. Sweet maize cultivars are in general, sensitive to rimsulfuron (Everaerer, 1991; Green & Ulrich, 1994). Moreover, a relation between maize heat requirements and sensitivity to rimsulfuron has been found. Some early maturiting maize genotypes with a maize heat units (MHU) requirement of = 2 400, particularly 'Flint' cultivars (*Z. mays 'indurata'*) were found to be susceptible to rimsulfuron (DuPont Canada, *pers. com.*). Also, the rimsulfuron label directs growers to avoid the use of rimsulfuron in maize cultivars 'Funk's 4120', '4160', and '4034' (Anonymous, 1996).

Maize tolerance to rimsulfuron is based on the differential rate of metabolism of the active compound to inactive metabolites, as compared to that of sensitive weed species (Palm *et al.*, 1989). Rimsulfuron has a half-life of only six hours in maize leaves, whereas in sensitive species, such as *Alopecurus myosuroides*, *Sorghum halepense*, and *Sorghum bicolor*, the half-lives are much longer, from 25 to 52 hours (Palm *et al.*, 1989).

Nicosulfuron, primisulfuron, thifensulfuron, prosulfuron and halosulfuron are postemergence sulfonylurea herbicides that were recently developed and registered in various countries for selective weed control in maize (Camacho *et al.*, 1991; Bhowmik *et al.*, 1992; Copping, 1995; Gubbica *et al.*, 1995; Williams & Harvey, 1996). Response of maize cultivars to these herbicides can vary widely. Differential tolerance among both sweet and field maize cultivars to nicosulfuron, primisulfuron, and thifensulfuron has been reported (Eberlein *et al.*, 1989; Monks *et al.*, 1992; Morton & Harvey, 1992; Stall & Bewick, 1992; Green & Ulrich, 1993; Robinson *et al.*, 1993; O'Sullivan *et al.*, 1995; Williams & Harvey, 1996). However, Morton *et al.* (1991) reported that some cultivars tolerate nicosulfuron at doses higher than 140 g a.i. ha^{-1}. Differential tolerance among maize genotypes to other sulfonylurea herbicides has also been reported, e.g. to chlorsulfuron (Landi *et al.*, 1989).

It has been demonstrated that temperature is of primary importance in determining the rate of development of maize. The length of growing season (frost-free period), temperature, and, to some extent, photoperiod, determine the climatic region in which a genotype is adapted. When a maize hybrid is grown in its region of adaptation, temperature variations are the primary cause of year to year and location to location variations in rate of development. It is for this reason that the maturation time of maize genotypes has been found to be most closely related to the accumulation of thermal units (Major *et al.*, 1983; Dubé *et al.*, 1984).

Thermal unit systems for evaluating the development and maturation time of crop plants have taken many forms. Temperatures above a base temperature are usually accumulated on a daily basis. A thermal unit system based on a non linear response of maize to daytime temperatures was introduced into Ontario, Canada in 1964 for maize hybrid recommendations. The system has been given the name Maize Heat Unit (MHU), although it is also referred to as the Ontario Heat Unit rating system for maize hybrids. A MHU zonation map was included in climates of Canada for agriculture (Major *et al.*, 1983). The purpose of the MHU system is to characterize each region by the most likely number of MHU available to mature maize in each growing season, and to characterize hybrids by their MHU requirements (Major *et al.*, 1983; Dubé *et al.*, 1984).

The system permitting characterisation of hybrid maize thermal requirements and regionalization of this crop in Québec, uses the synthetic index 'MHU'. Daily calculation of MHU is carried out as follows. Thermal units represent values derived from mathematical functions which describe the existing relationship between temperature (T) and the plant's development rate (Y). The concept calls upon two distinct mathematical relationships: one for the temperature in diurnal periods $[Y_{max} = 3.33\ (T_{max} - 10.0)^2]$, and another for nocturnal period temperature $[(Y_{min} = 1.80\ (T_{min} - 4.4)]$ (Dubé *et al.*, 1984). Daily MHU accumulation is calculated from two daily air temperature values measured in the shade: maximum (diurnal) and minimum (nocturnal). The following equation illustrates the calculation of daily MHU:

$$MHU_{daily} = (Y_{max}\ \text{value} + Y_{min}\ \text{value})/2$$

Sums of MHU daily values are accumulated during the growing season. The seasonal total of MHU is obtained by addition of daily MHU from the beginning to the end of the maize growing season (Dubé *et al.*, 1984). The Ontario and Québec maize committees do not start accumulating MHU until the mean temperature is 12.8°C, and stop when the probability of occurrence of 0°C temperature is 10% (Major *et al.*, 1983; Dubé *et al.*, 1984).

The Québec crop production board (CPVQ) has the task of determining the thermal requirements of maize cultivars by means of an assay network in the Québec agricultural region. This is accomplished by comparing new cultivars to be tested with control cultivars which are adapted to each zone. Three years of evaluation are required before a particular maize cultivar can be recommended for a given zone. It is in this manner that specific cultivar recommendations result based upon their MHU requirements and the already established climatic zones (Dubé, *com. pers.*).

A seasonal total equal or greater than 2 500 MHU assures field maize production; forage maize production requires at least 2 100 MHU. Taking into account thermal requirements of maize production, Québec zones 1 and 2 are favourable to field maize production. In the case of forage maize, zones 1, 2, 3 and 4 are appropriate to this production (Figure 1) (Dubé *et al.*, 1984).

Crop varietal sensitivity is an important factor to consider in the commercial use of sulfonylurea herbicides. The main objective of this research was to characterize the level of tolerance of eighteen maize hybrids to rimsulfuron under field conditions and to determine differences in sensitivity to this herbicide of the hybrids adapted to three climatic zones of Québec.

MATERIALS AND METHODS

General procedure

Eighteen field maize hybrids with various maize heat unit (MHU) requirements were evaluated under field conditions on the campus of Université Laval (Ste. Foy-Québec, Canada) in the summers of 1992 and 1993 (Table 1). All hybrids were either used commercially or under testing for approval. The hybrids were adapted to three different climatic zones of Québec: zone 1: > 2 700 MHU; zone 2: 2 500 to 2 700 MHU, and zone 3: 2 300 to 2 500 MHU (Figure 1). Six hybrids of each zone were tested.

The soil was prepared with conventional tillage. No herbicides other than rimsulfuron were used. Weeds surviving the rimsulfuron were controlled by hoeing. No insecticides or fungicides were used. In both years, 169 Kg N, 150 Kg P and 50 Kg k ha^{-1} was applied prior to planting. Maize hybrids were sown manually at 5 cm depth with two seeds per position and 20 cm between positions. Rows were 60 cm apart with plots consisting of two rows of 1.50 m length. Maize seedlings were thinned to one plant per position (*ca.* 73 000 plants ha^{-1})

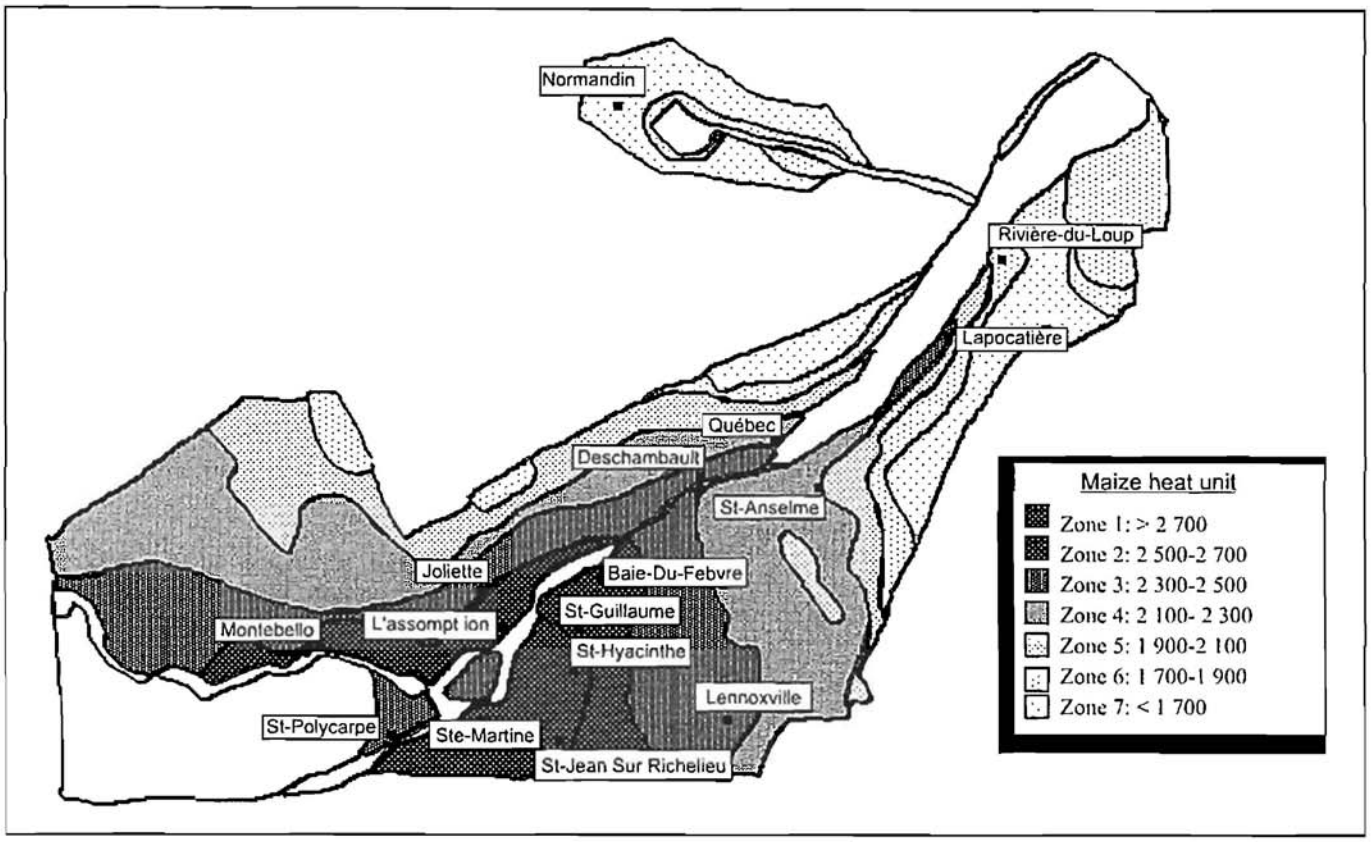

Figure 1. Maize heat units (MHU) distribution chart in Québec, Canada. Period 1970 to 1978. Probability: 80%, or summation of 8 out of 10 years (After Dubé *et al.*, 1984).

Table 1. Maize hybrids adapted to three zones of Québec tested in 1992 and 1993.

Zone 1: > 2 700 MHU	**Zone 2: 2 500 to 2 700 MHU**	**Zone 3: 2 300 to 2 500 MHU**
1. Cargill 2037	7. Hyland HL 2241	13. Hyland HL 3195
2. Cargill 2127	8. Hyland HL 2212	14. Hyland HL 2262
3. Hyland HL 2272	9. Pickseed 2620	15. Pioneer 3967
4. Hyland HL 2334	10. Pioneer 3897	16. Pioneer 3979
5. Pickseed 4990	11. Pioneer 3917	17. Pride-Figaro
6. Pioneer 3751	12. Pioneer 3953	18. Pride 1- 251

ten days before applying rimsulfuron (*i.e.* three days after emergence in 1992 and four days in 1994).

When maize plants bore four to five leaves (15 to 20 cm tall), rimsulfuron was applied at 20, 40, and 60 g a.i ha^{-1} in a mixture with a non-ionic surfactant at 0.2% (v/v) dose (AGRAL 90™, nonylphenoxypolyethoxy ethanol; Zeneca Agro, Longueil, Québec, J4G 1R9). An untreated hand-weeded control treatment for each hybrid was also included. The rimsulfuron labelled dose of one single application is 15 g a.i ha^{-1} (ELIM EP™) (Anonymous, 1996). When we started this work in 1992, rimsulfuron was not registered in Canada. So, we used the the dosage recommended in France of 20 g a.i ha^{-1} (TITUS™) (Everaerer, 1991). Evaluating crop response to increasing dosage of herbicides is useful in the prediction of injury levels when the crop will be exposed to abnormal doses under field conditions (Clay, 1985).

In both years, rimsulfuron was applied using a bicycle-mounted compressed air sprayer delivering 225 L ha^{-1} at 200 kPa pressure and equipped with flat-fan nozzle tips. Sowing and application conditions are reported in Table 2 for both 1992 and 1993.

Table 2. Planting and application conditions for rimsulfuron treatment in 1992 and 1993.

	1992			**1993**		
Planting date	26 May			17 May		
Day of emergence	5 June			6 June		
Application date	17 June			17 June		
Sky condition	Clear			Cloudy		
Time of application	7:10 to 7:50 a.m.			8:00 to 8:40 a.m.		
Air temperature (°C)	Max.	Min.	Average†	Max.	Min.	Average†
16 June	24.0	5.0	14.5	22.0	14.0	18.0
17 June	28.0	9.0	18.5	24.0	10.0	17.0
18 June	30.0	14.0	22.0	17.0	15.0	16.0
19 June	27.0	17.0	22.0	26.0	13.0	19.5
Rainfall (mm)						
May	62.2			124.6		
June	97.4			102.2		
July	256.4			116.0		
August	116.0			107.0		

†Average temperature = (T°max + T°min)/2

The normal average air temperature from June 11 to 22 is 16.9°C. Effective MHU from June 11 to 20 were 222.6 in 1992 and 203.4 in 1993; the normal effective MHU for the same period is 195.9.

The response of the maize hybrids to rimsulfuron was evaluated in relation to the control treatments. Different variables were measured at different dates to assess the damage caused by rimsulfuron to the maize hybrids. Tolerance to rimsulfuron was evaluated by means of: (1) visual phytotoxicity, (2) plant height, and (3) above-ground dry weight. Visual phytotoxicity was evaluated every seven days after the rimsulfuron treatment (DAT) during 35 days, using a visual scale where 0 = no maize vigour reduction and 100 = death of maize. Data on plant height and above-ground dry weight were taken from five plants randomly selected at the beginning of the experiment from the mid-length portion of both rows in each plot. Plant height was evaluated on three dates (10, 20, and 30 DAT), measuring from the ground level to the tip of the youngest completely expanded leaf. Above-ground dry weight was recorded at 64 DAT in 1992 and 1993. To adjust for differences in growth between hybrids, the data for height and dry weight were expressed as percentages of the untreated control.

Data analysis

The experiment was conducted as a split-block design with two factors and three blocks. Factor A was the maize genotype and factor B was the rimsulfuron dose. Data was subjected to standard analysis of variance (ANOVA).

Principal component analysis (PCA) was also conducted (Kendall, 1980; Morrison, 1990). This analysis was performed on the aggregate data of all variables, dates of evaluation, doses and years. Multivariate statistical methods are applied when there are several variables of interest and these are not clearly independent of each other (Manly, 1986), as is the case of the present work.

PCA is designed to reduce the number of variables that need to be considered to a small number of indices (called the 'Principal Components') that are linear combinations of the original variables. Each component reflects a different 'dimension' of the data (Kendall, 1980; Karson, 1982; Manly, 1986). PCA provides an objective way of finding indices of this type as concisely as possible. Also, PCA may be used to explain or understand the variability of data (Karson, 1982). One or two components provide in general, a good summary of all the original variables. Consideration of the values of the principal components instead of the values of the original variables may then make it much easier to understand the true meaning of the data. In short, PCA is a mean of simplifying data by reducing the number of variables (Manly, 1986).

The aim of PCA is to resolve the total variation in a set of variables into linearly independent composite variables which successively account for the maximum variability of the data. The unique linear combinations of the original variables that satisfy these successive variance maximization criteria are the eigenvectors, or principal axes of the covariance or correlation matrix, among variables, weighted by the square root of the respective eigenvalues. Each principal component (PC) is proportional to the variance it explains, and the eigenvalues are the variances of the composite variables along their PC axes (Kendall, 1980; Morrison, 1990).

RESULTS

Interactions of year by treatment (year by dose and year by hybrid) were significant for all variables (F test; Table 3). Therefore, data were analyzed separately by year.

Table 3. F-statistics and error mean squares for combined analysis of the mean of visual Phytotoxicity (%) at 14, 21, 28 and 35 days after rimsulfuron treatment, for 1992 and 1993.

Source of variation	df	F -statistic
Year	1	2303.27 **
Block (Year)	4	3.17 *
Hybride (Hyb)	17	88.04 **
Error mean square (a)	68	*24.95*
Dose	2	333.01 **
Error mean square (b)	8	*18.36*
Year x Hyb	17	113.40 **
Hyb x Dose	34	2.00 **
Year x Dose	2	59.19 **
Year x Hyb x Dose	34	4.32 **
Error mean square (c)	136	5.95
Total	323	

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

Visual phytotoxicity to maize was on average, more severe in 1992 (32% to 46%) than in 1993 (11% to 23%), with respect to the date of evaluation (Figure 2). In general, maize hybrids started to recover from the rimsulfuron damage by 21 DAT in 1992, and by 14 DAT in 1993 (Figure 2). All hybrids exhibited spotted chlorosis in younger leaves of the whorl. In tolerant hybrids, this chlorosis disappeared by 7 DAT. When damage was more severe in sensitive hybrids, symptoms included leaf base widening and failure of the leaves to unfurl. If the growing point was severely injured, loss of apical dominance resulted in the development of one or more tillers.

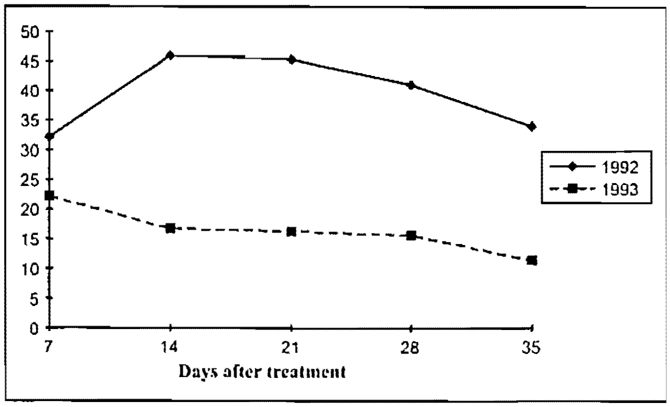

Figure 2. Average percentage of visual phytotoxicity in maize hybrids at 7, 14, 21, 28 and 35 DAT in 1992 and 1993. Data are means of 3 rimsulfuron doses, 18 maize hybrids and 3 blocks. S'y 1992 = 1.29; S'y 1993 = 1.52.

Coefficients of correlation (r) between each variable recorded were all significant (P = 0.01) (Table 4). In general, visual score evaluated at 14, 21, 28 and 35 DAT showed the strongest inter-relationship, in both 1992 and 1993. For these variables, r varied from 0.89 to 0.96 in 1992, and from 0.67 to 0.92 in 1993.

PCA indicated that the first principal component (PC_1) accounted for 82% of the total variance, whereas components one to nine all have variances very much less, and accounted jointly for the remaining 18% of the total variance. This means that PC_1 was by far the most important of the nine components for representing the variation in the measurement of phytotoxicity of rimsulfuron in maize hybrids. PC_1 can be thought of as a simple index of herbicide

Table 4. Correlation matrix among variables evaluated for rimsulfuron tolerance for the combined data of eighteen maize hybrids and three doses, for 1992 and 1993.

		1992								
		Injury † 7 DAT‡	Injury 14 DAT	Injury 21DAT	Injury 28 DAT	Injury 35 DAT	Height¶ 10 DAT	Height 20 DAT	Height 30 DAT	DryWeight 64 DAT¶
	Injury 7 DAT	1	0.6934	0.7012	0.6913	0.6746	0.6570	0.6981	0.6413	0.6178
	Injury 14 DAT	0.8475	1	0.9210	0.9276	0.8903	0.6524	0.8533	0.7850	0.6263
1	Injury 21 DAT	0.7715	0.9177	1	0.9627	0.9338	0.6284	0.8767	0.7963	0.6541
9	Injury 28 DAT	0.6680	0.7766	0.8394	1	0.9612	0.6565	0.9048	0.8535	0.6616
9	Injury 35 DAT	0.6068	0.6670	0.6961	0.8662	1	0.6006	0.8978	0.8654	0.6787
3	Height 10 DAT	0.6558	0.7332	0.6804	0.5821	0.4314	1	0.6436	0.5598	0.5061
	Height 20 DAT	0.5660	0.6979	0.6800	0.5950	0.4547	0.8379	1	0.8936	0.7317
	Height 30 DAT	0.1551	0.2214	0.1912	0.3902	0.5279	0.0629	0.2021	1	0.6953
	Dry Weight 64 DAT	0.2485	0.3339	0.3219	0.4086	0.3760	0.2336	0.3010	0.4301	1

† Visual phytotoxicity
‡ DAT= Days after rimsulfuron treatment
¶ Height and dry weight were expressed as percent of the untreated control
All correlation coefficients are significant at P=0.01 level. The number of observations was 324 for each correlation.

phytotoxicity. The 'eigenvector' values of PC_1 and PC_2 are presented in Table 5. The 'eigenvector' values of visual phytotoxicity at 14, 21, 28, and 35 DAT in PC_1 were higher than those of the other variables and varied around 0.36 (Table 5). This signified that comparison among hybrids for sensitivity to rimsulfuron could be carried out by means of the analysis of visual phytotoxicity evaluated at 14, 21, 28, or 35 DAT. Therefore, we considered the mean of visual score at 14, 21, 28 and 35 DAT as the variable to be analyzed (Table 6).

Table 5. Principal component analysis. Eigenvector values of nine variables evaluated for maize tolerance to rimsulfuron for combined data of eighteen maize hybrids, three doses, and two years.

Variable **Proportion of variance explained:**	**Principal Component 1** **Eigenvalue: 7.4094** **0.823**	**Principal Component 2** **Eigenvalue: 0.5647** **0.886 (cumulative)**
Visual phytotoxiciy 7 DAT†	0.289886	0.366870
Visual phytotoxiciy 14 DAT	0.366077	0.180634
Visual phytotoxiciy 21 DAT	0.368928	0.071902
Visual phytotoxiciy 28 DAT	0.365793	0.011277
Visual phytotoxiciy 35 DAT	0.363152	-0.014691
Height 10 DAT	-0.319489	-0.314004
Height 20 DAT	-0.343467	-0.0998684
Height 30 DAT	-0.298239	0.501965
Dry weight 64 DAT	-0.266781	0.683344

†DAT: Days after treatment

Sensitivity of hybrids to rimsulfuron as well as differences due to rimsulfuron doses and the hybrid (intrazone) by dose interaction, were highly significant in both 1992 and 1993 (Table 6). This interaction hybrid (intrazone) was significant (except for zone 1 in 1993), suggesting that hybrids within each zone react differently to different doses of rimsulfuron (Table 6).

Table 6. F-statistics and error mean squares for analysis of the mean of visual phytotoxicity (%) at 14, 21, 28 and 35 days after rimsulfuron treatment, for 1992 and 1993.

		1992	**1993**
Source of variation	**Df**	**F-statistic**	**F-statistic**
Block	2	4.98 *	0.35 **
Zones (Z)	2	800.37 **	285.64 **
Hybrid (intrazone)	15	49.0953 **	46.95 **
Hybrid (Z1)	5	55.59 **	2.41 *
Hybrid (Z2)	5	65.07 **	7.45 **
Hybrid (Z3)	5	26.64 **	19.80 **
Error mean square (a)	34	*17.08*	*32.83*
Dose	2	244.12 **	260.58 **
Error mean square (b)	14	*19.11*	*17.61*
Zone x Dose	4	2.02 ns	6.83 **
Hyb (Z) x Dose	30	3.23 **	2.73 **
Hyb (Z1) x Dose	10	2.41*	1.46
Hyb (Z2) x Dose	10	2.45**	3.34**
Hyb (Z3) x Dose	10	19.80**	3.39**
Error mean square (c)	68	*4.98*	*6.91*
Total	161		

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

Figure 3 shows the response of two hybrids of each zone, with opposite performance. 'Cargill 2127', 'Pickseed 2620' and 'Hyland HL 2262' were amongst the most tolerant hybrids of zones 1, 2 and 3, respectively. 'Hyland HL 2272', 'Pioneer 3897' and 'Pionner 3979', were amongst the most sensitive ones of zones 1, 2 and 3, respectively. Some hybrids tolerate a high dose of rimsulfuron (60 g a.i. ha^{-1}) showing less than 20% injury (*e.g.* 'Cargill 2127', 'Hyland HL 2272', 'Pickseed 2620' and 'Hyland HL 2262' in 1993) while others were severely injured at a low dose (20 g a.i. ha^{-1}), with more than 20% injury (*e.g.* 'Hyland HL 2272', 'Pioneer 3897', 'Hyland HL 2262', and 'Pionner 3979' in 1993). No growers will accept a herbicide injury greater than 20%.

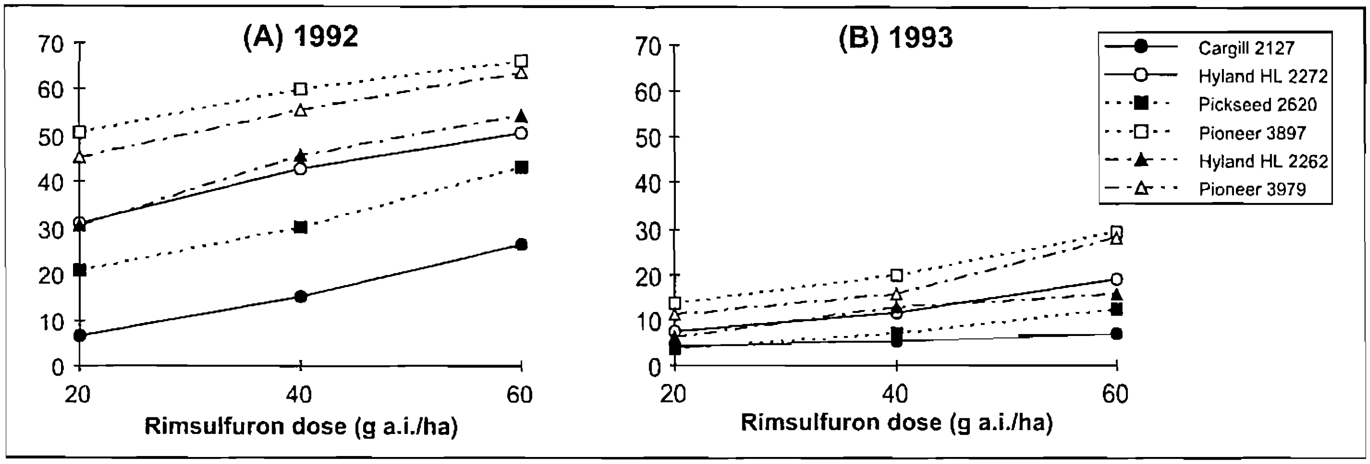

Figure 3. Visual phytotoxicity (mean of visual phytotoxicity across 4 dates of evaluation: 14, 21, 28 and 35 DAT) of six maize hybrids adapted to three climatic zones of Québec , and treated with three doses of rimsulfuron, in (A) 1992 and (B) 1993. Zone 1(>2 700 MHU): 'Cargill 2127' and 'Hyland HL 2272'; zone 2 (2 500 to 2 700 MHU): 'Pickseed 2620' and 'Pioneer 3897'; zone 3 (2 300 to 2 500 MHU): 'Hyland HL 2262' and 'Pioneer 3979'. Data are mean of 3 blocks. S'y 1992 = 1.80; S'y 1993 = 1.1.87.

In general, hybrids from zone 1 were more tolerant than hybrids of zone 2 and 3. Visual phytotoxicity (mean of visual score across four dates of evaluation and three doses) varied from 13% to 42% in 1992, and from 10% to 13% in 1993. In contrast, injury of hybrids of zone 2 varied from 31% to 62% in 1992, and from 8% to 18% in 1993. Hybrids of zone 3 were more severely affected; in 1992, visual score varied from 42% to 60%, and from 13% to 32% in 1993 (Table 7). If one considers that full labelled dose of a single rimsulfuron application is 15 g

Table 7. Hybrid phytotoxicity score (HPS) of eighteen maize hybrids based on the mean of visual phytotoxicity at 14, 21, 28 and 35 days after treatment and all three application doses (20, 40, and 60 g a.i. ha-1) of rimsulfuron. Hybrids were grouped into three categories accordingly to their phytotoxicity score. Group I: PS < 0; Group II: PS ≅ 0; Group III: PS > 0.

Hybrid‡	Visual phytotoxicity† (%)		Year mean minus (-) visual phytotoxicity		HPS (Sum of 1992 and 1993)	Category of Tolerance
	1992	1993	1992	1993		
1.Cargill 2037	25.83	7.91	-15.85	-7.13	-22.98	I
2.Cargill 2127	16.11	5.55	-25.57	-9.50	-35.07	I
3. Hyland HL 2272	42.22	12.78	-0.54	-2.28	-2.82	I
4. Hyland HL 2334	13.33	10.28	-28.35	-4.77	-33.12	I
5.Pickseed 4990	19.86	13.47	-21.82	-1.58	-23.40	I
6.Pioneer 3751	22.78	10.14	-18.91	-4.91	-23.82	I
7. Hyland HL 2241	53.47	8.61	+11.79	-6.44	+5.35	III
8. Hyland HL 2212	46.67	11.67	+4.98	-3.38	+1.60	III
9. Pickseed 2620	31.53	7.78	-10.16	-7.27	-2.89	I
10. Pioneer 3897	59.03	20.83	+17.35	+5.78	+23.13	III
11. Pioneer 3917	44.17	13.05	+2.49	-2.00	-0.49	II
12. Pioneer 3953	61.80	18.19	+20.12	+3.14	+23.26	III
13. Hyland HL 3195	53.75	27.50	+12.07	+12.45	+24.52	III
14. Hyland HL 2262	43.75	12.64	+2.07	-2.41	-0.34	II
15. Pioneer 3967	43.19	13.61	+1.51	-1.44	+0.07	II
16. Pioneer 3979	55.00	16.39	+13.32	+1.34	+14.66	III
17. Pride Figaro	59.44	28.33	+17.76	+13.28	+31.04	III
18. Pride 1-251	58.33	32.08	+16.65	+17.03	+33.68	III
Year mean	41.68	15.05				

† Mean of visual phytotoxicity accross three doses and four dates of evaluation (14, 21, 28 and 35 DAT).

‡ Hybrids 1 to 6 are adapted to zone 1 of Québec: > 2 700 MHU; Hybrids 7 to 12 are adapted to zone 2 of Québec: 2 500 to 2 700 MHU; Hybrids 13 to 18 are adapted to zone 3 of Québec: 2 300 to 2 500 MHU.

a.i ha^{-1} (ELIM EP™; DuPont Canada Inc., Mississauga, Ontario, L5M 2J4; Anonymous, 1996), hybrids of zone 1 could be considered tolerant. When this work was started in 1992, rimsulfuron was not registered in Canada. Therefore the recommended dosage in France of 20 g a.i ha^{-1} was used (TITUS™; DuPont de Nemours, Paris, France; Everaerer, 1991).

Sensitive hybrids did not recover even after 35 DAT. In contrast, tolerant hybrids recovered quickly, since their highest visual injury was observed from 14 to 21 DAT (individual data not shown). Where present, recovery of hybrids from the injury caused by rimsulfuron could be expected by 35 DAT.

With the aim of elucidating the positive relation between hybrid tolerance to rimsulfuron and MHU requirements, a regression analysis was performed (Figure 4). In both 1992 and 1993, regression was significant (P = 0.0001). This indicates that there is dependence of visual phytotoxicity on MHU requirements, specially in 1992 when the R^2 was higher than in 1993 (Figure 4). The higher R^2 in 1992 than in 1993 could be explained because hybrids were more severely injured in 1992 than in 1993.

A 'Hybrid Phytotoxicity Score' (HPS), based on the mean of visual phytotoxicity at 14, 21, 28 and 35 DAT, and averaged across all three application doses, was calculated. The data from both years were summed by normalizing this HPS each year as a +/- value of the mean phytotoxicity score of the same year (Table 7). A negative value of HPS indicates that a hybrid was injured less than the average of hybrids in each year. A positive value of HPS indicate that a cultivar was affected more than the average of cultivars. A HPS value equal or close to zero means that the response of a hybrid to the herbicide was similar to the mean of hybrids. Accordingly to this HPS, hybrids were grouped into three categories with regards to their degree of tolerance: I. Tolerant (HPS < 0); II. Moderately tolerant (HPS ≅ 0); and III. Sensitive (HPS > 0). All hybrids of zone 1 were classified as tolerant to rimsulfuron (Group I): 'Cargill 2127', 'Cargill 2037', 'Hyland HL 2272', 'Hyland HL 2334', 'Pickseed 4990' and 'Pioneer 3751'. In zone 2, one hybrid was classified as tolerant (Group I: 'Pickseed 2620'), one was intermediate (Group II: 'Pioneer 3917', and four hybrids were sensitive (Group III: 'Hyland HL 2241, 'Hyland HL 2212', 'Pioneer 3897', and 'Pioneer 3953'). Four of six hybrids of zone 3 were sensitive (Group III: 'Hyland HL 3195', 'Pioneer 3979', 'Pride-Figaro', and 'Pride 1-251'), and two were moderately tolerant (Group II: 'Hyland HL 2262' and 'Pioneer 3967'). No hybrids of zone 3 were tolerant (Table 7).

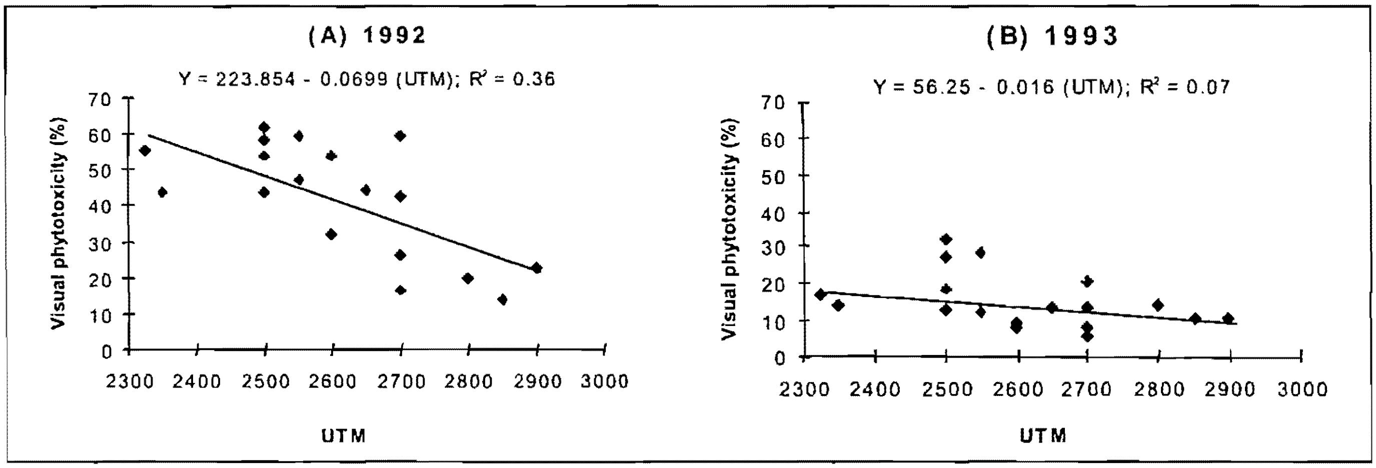

Figure 4. Regression between visual phytotoxicity (mean of visual phytotoxicity across three rimsulfuron doses and four dates of evaluation: 14, 21, 28 and 35 DAT) and MHU requirements, in 1992 and 1993.

DISCUSSION

Injury symptoms exhibited by maize hybrids were similar to those described by Morton & Harvey (1992) and Monks *et al.* (1992) on sweet maize, and to those in the description by Siminszky *et al.* (1995) on field maize when using nicosulfuron. In this research, all hybrids developed at least the spotted chlorosis symptom. The appearance and intensity of other symptoms depended on the tolerance of the different hybrids to rimsulfuron. Tolerant hybrids recovered from damage by 14 to 21 DAT, even at the highest rimsulfuron dose. Doohan *et al.* (1995) reported that light injury caused by rimsulfuron: nicosulfuron (1:1 premix) disappeared seven days after treatment, but when injury was severe in the sensitive 'Dekalb 291' genotype, 40% of the plants died within a month of treatment.

Morton & Harvey (1992) and O'Sullivan *et al.* (1995) evaluated the tolerance of sweet maize hybrids to nicosulfuron and to nicosulfuron:rimsulfuron (1:1 premix), respectively. The magnitude of injury varied from year to year, findings which were consistant with the results of our research. The magnitude of injury may also vary between sites. Doohan *et al.* (1995) noticed variable injury in maize hybrids treated with nicosulfuron:rimsulfuron (1:1 premix) in three sites of eastern Canada. However, Santos *et al.* (1995) did not observe differences in the tolerance of field maize when rimsulfuron was applied at three sites in southern England. Environmental conditions could account for maize cultivar variations in tolerance to sulfonylurea herbicides between years and sites. Air temperature, relative humidity and soil moisture variation, either a few days before or after the sulfonylurea treatments, may be responsible for differential crop tolerance response to those compounds (Morton & Harvey, 1992; Beyer *et al.*, 1988; O'Sullivan *et al.*, 1995; Swanton *et al.*, 1996). Maximum, minimum and average temperatures of the day when rimsulfuron was applied and of the following days were higher in 1992 than in 1993 (Table 2). Effective MHU accumulated from June 11 to June 20 were also higher in 1992 than in 1993 (Table 2). This could explain the greater maize injury observed in 1992 as compared to 1993 (Figure 2).

Visual phytotoxicity of maize hybrids followed a linear trend in response to dose of rimsulfuron. Increases in tillering and reduction in both height and yield of maize have also been reported to be related linearly to the dose of DPX-79406 (Swanton *et al.*, 1996). However, Morton & Harvey (1992) reported that, for sweet maize, visual phytotoxicity over the nicosulfuron-tested doses was best described as a quadratic response.

The degree of injury caused by rimsulfuron to maize hybrids in the present study depended on the genotype as well as the dose. Other studies with sweet maize using DPX-79406 (O'Sullivan *et al.*, 1995) or nicosulfuron in mixture with primisulfuron (Monks *et al.*, 1992) reported similar results. Morton & Harvey (1992) reported that only 'Jubilee', out of eight sweet maize cultivars treated with nicosulfuron, was severely injured. Doohan *et al.* (1995) also indicated that, out of 18 early maturing field maize hybrids only 'Dekalb 291' and 'Dekalb 235' were susceptible to nicosulfuron:rimsulfuron (1:1 premix). In the present study, differential tolerance of field maize hybrids to rimsulfuron was identified. Rimsulfuron could be used safetly for commercial maize production in zone 1 of Québec (> 2 700 MHU). The use of rimsulfuron in zones 2 and 3 of Québec depends on the maize hybrid. Most of sensitive hybrids were from zones 2 and 3. As it was mentioned previously, zone 3 is not a highly important zone for field maize production in Québec, as compared with zone 1. Therefore, the use of rimsulfuron in Québec could be considered a good tool in weed management for maize production.

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