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Response of Johnsongrass Biotypes from Humid and Subhumid Regions to Nicosulfuron in Argentina

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Abstract

The response of seven Johnsongrass (*Sorghum halepense* L. Pers.) biotypes from humid and subhumid regions to reduced rates of nicosulfuron was evaluated. Variability in performance to reduced rates of this herbicide could limit the design and implementation of integrated weed management programs. The three biotypes from subhumid regions were less sensitive to nicosulfuron and differed significantly from the humid biotype with regards to fresh weight, total rhizome length, and number of rhizomes nodes when evaluated 20 weeks after treatment. Consequently, a substantial Johnsongrass re-infestation could occur if rates below one-half of the nicosulfuron labeled rate were used to control Johnsongrass in subhumid regions. These biotypes showed a significant difference in regrowth following reduced rates of nicosulfuron compared to the biotype from the humid region. According to the results of Johnsongrass regrowth, the use of rates below one-half of nicosulfuron labeled rate must be avoided in these environments and the use of nicosulfuron at lower rates is not a viable recommendation.

Introduction

Johnsongrass (*Sorghum halepense* L. Pers.), an aggressive perennial grass, is considered one of the world's worst weeds (8). This species has proved troublesome in the extensive cropping systems of Argentina (12), despite continued selective postemergence (POST) herbicide use.

An increasing pressure on the farmer to reduce herbicide use for both environmental and economic reasons (2) has to helped to promote to the development of integrated weed management (IWM) programs. Reduced rates of herbicides could be a beneficial alternative to include in such programs (2). However, limited studies have been conducted concerning the use of reduced herbicide rates on Johnsongrass.

In glyphosate-resistant soybean fields of Argentina, cases of glyphosate-resistant Johnsongrass were reported where glyphosate has been used extensively (18). The exclusive reliance on glyphosate as the main tool for weed management results in selection for glyphosate resistance (19). In this context, the recommendations of the Herbicide Resistance Action Committee (2011) for weed resistance management include the use of multiple herbicide modes of action with overlapping weed spectrums in rotation, sequences, or mixtures.

Studies based on a Johnsongrass population indicate that reduced herbicide rates of both nicosulfuron and clethodim provided an adequate Johnsongrass control (10,15). However, the effectiveness of this technology has been related to several factors such as weed spectrum, environmental conditions, weed populations, and herbicide mode of action (5). Weeds tend to adapt quickly to selection pressure and produce a wide variety of genotypes that can be fit to a range of environments (2).

Nicosulfuron is classified as a sulfonylurea herbicide currently registered for post-emergence control of grass and broadleaf weeds in corn (17) and this herbicide was among the ten most traded in Argentine markets due mainly to the good control of Johnsongrass (11).

Despite the abundant knowledge on Johnsongrass ecophysiology (1), little work has focused on the response of Johnsongrass populations when treated with reduced rates of herbicides (14). The objective of this work was to determine the behavior of several Johnsongrass biotypes of different origins to reduced rates of nicosulfuron. Information concerning the possible differential performance of the populations could limit the design and implementation of IWM programs in different crop production systems.

Evaluating Response of Seven Biotypes to Nicosulfuron Rates

Plant materials. Rhizomes of seven Johnsongrass biotypes were originally collected from agricultural fields of four Argentinean provinces (La Pampa and Córdoba from subhumid region and Buenos Aires and Entre Ríos from humid region). The geographic location of Johnsongrass biotypes are shown in Figure 1.

Rhizomes were trimmed to two node sections; rhizome sections averaged 4 to 7 g. These pieces were washed free of soil, soaked in a solution of 0.35 g/liter benomyl for 10 min to retard decay, and layered in trays filled with sand. Trays were stored in a growth chamber where temperature and relative humidity were 25°C and 65%, respectively.

Biotypes response to reduced rates of nicosulfuron. Two outdoor experiments with pots were conducted at La Plata National University Station (34°S, 57°W, La Plata, Argentina). Johnsongrass biotypes were grown from sprouted rhizomes in 30-liter pots filled with a mixture (1:1) of soil and vermiculite. The experiments were planted on 11 October 2004 and 6 October 2005. Plants were thinned to two per pot four days after emergence. At planting, pots were fertilized with the equivalent of 100 kg/ha commercial fertilizer (18-46-0, N-P-K) as granules. Data were collected in the first three to six weeks of the growing cycle when Johnsongrass should be controlled to prevent crop losses greater than 5% (7). The Johnsongrass biotypes were watered every day with a calculated amount of water to simulate the rainfall regime of each location during the experiment.

Johnsongrass plants with four fully expanded leaves (leaf collar visible) were sprayed with nicosulfuron (2-[[[[(4,6-dimethoxy-2-pyrimidinyl) amino] carbonyl]amino] sulfonyl]-N,N-dimethyl-3-pyridinecarboxamide) on 8 November 2004 and 12 November 2005. Rates for herbicide were 0X (untreated control), 0.125X, 0.25X, 0.5X, 0.75X, 1.0X and 1.5X of the labeled rate (1.0X, 35 g ai/ha). A non-ionic surfactant at 0.25% (v/v) was added to the spray mixture. Estimates of Johnsongrass control (%) were based on fresh weight reduction compared to the untreated treatment. Johnsongrass plants were harvested four weeks after treatment (WAT); fresh aboveground biomass (g/pl) was recorded.

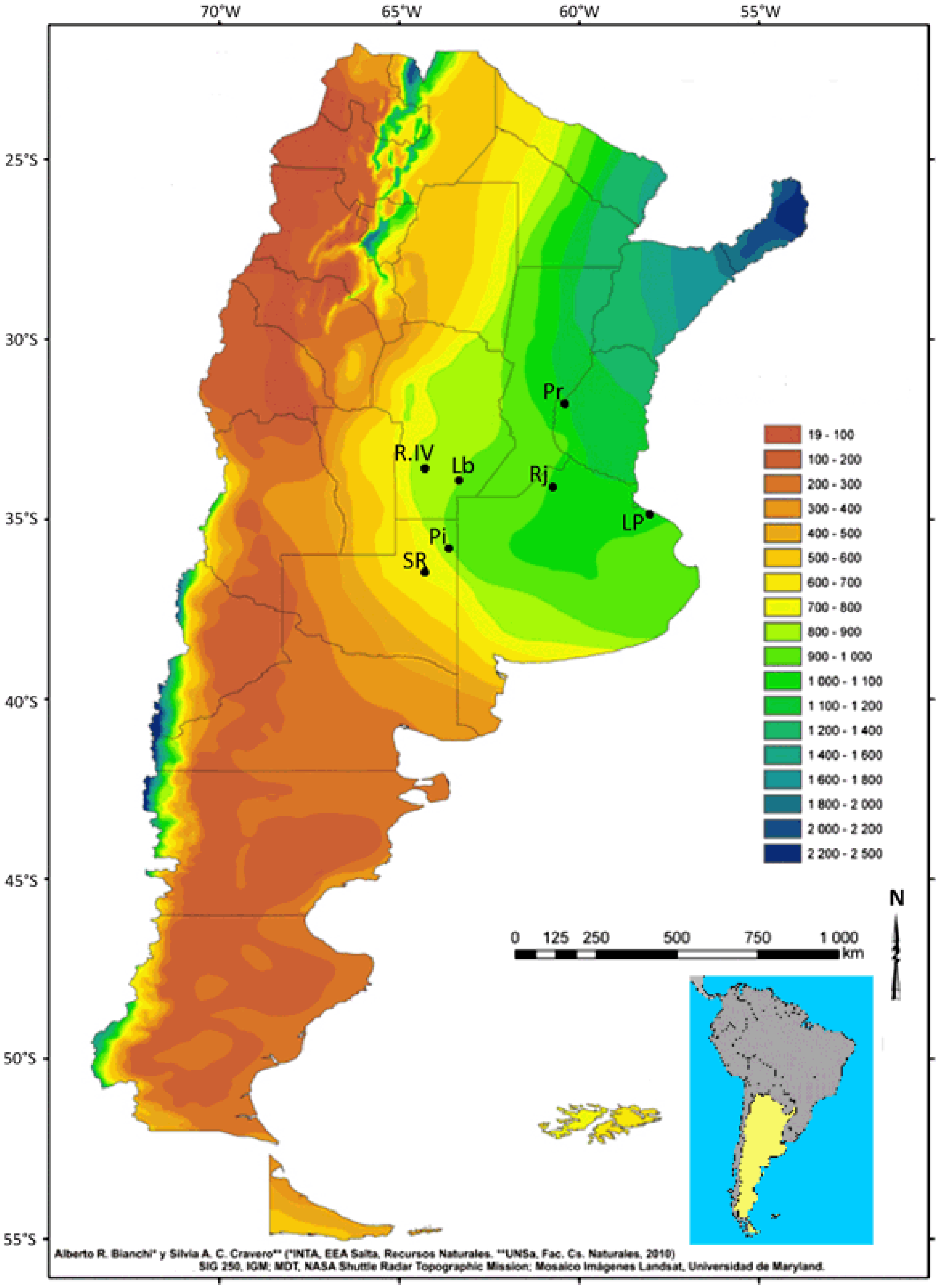

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Fig. 1. Geographic location of the seven Johnsongrass biotypes [Santa Rosa (SR), General Pico (Pi), Río Cuarto (R.IV), La Plata (LP), Rojas (Rj), Paraná (Pr) and Laboulaye (Lb)] and isohyetal lines of the mean precipitation for year (mm).

Statistical analysis. The factorial experiment was conducted in a randomized complete block design with five replications. The two factors were biotypes and nicosulfuron rate.

Nonlinear regression analysis techniques, similar to those employed by Chism et al. (4) were used to fit the Johnsongrass fresh aboveground biomass curves and to compare aboveground biomass in different biotypes. The following model often referred to as the Mitscherlich equation (4) was used:

$$y = a1 + a2^{(-a3*H)}$$

where Y is the weed fresh aboveground biomass (g), *a1* is the lower asymptote fresh aboveground biomass (g), *a2* is the aboveground biomass reduction form the upper to the lower asymptote (g), *a3* is the herbicide rate at which lower aboveground biomass is obtained (established as 1/X where the labeled herbicide rate is 1.0X) and *H* is the herbicide concentration in X. According to Rosales Robles et al. (14), a1 and a2 initial estimates were obtained from Figure 2 while initial value of a3 were obtained by the model:

$$a3 = \left[- \ln (y - a1) / a2 \right] / \mathrm{H}$$

An approximate coefficient of determination (R^2) was calculated to assess goodness of fit for individual non-linear equations by subtracting the ratio of the residual sums of squares (RSS) to the corrected total sums of squares (CTSS) from 1 i.e., $R^2 = 1 - RSS/CTSS$ [Carey et al. 1997 (3)]. Because a general non-linear model was used to generate aboveground biomass curves for all biotypes, comparisons between regression coefficients could be made using techniques described by Chism et al. (4) to establish significant differences between regression lines.

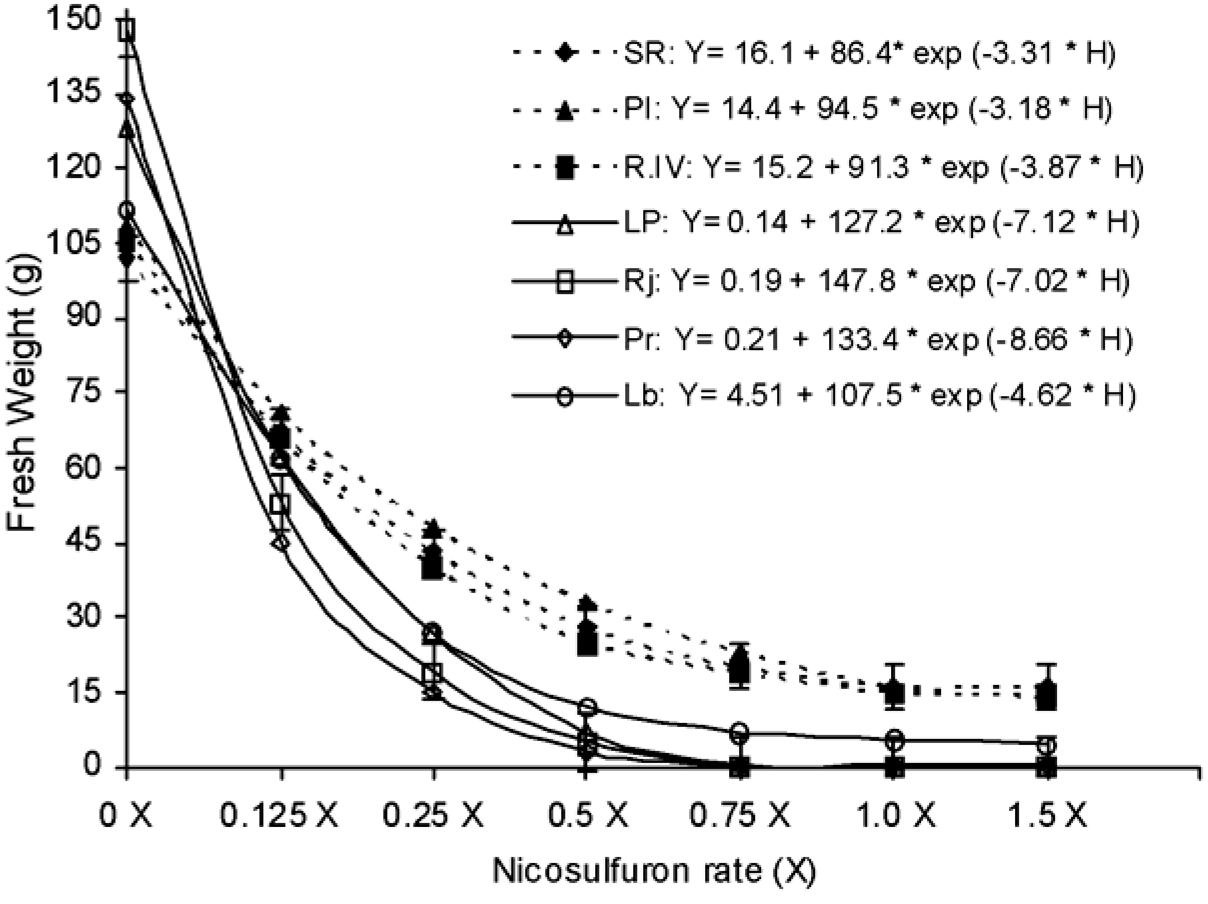

Fig. 2. Effect of reduced rates of nicosulfuron on fresh weight (g) of seven Johnsongrass biotypes, in Santa Rosa (SR), General Pico (Pi), Río Cuarto (R.IV), La Plata (LP), Rojas (Rj), Paraná (Pr), and Laboulaye (Lb), according to nonlinear regression equation: $y = a1 + a2^{(-a3*H)}$.

The statistical package Statgraphics plus 5.1 (StatPoint Technologies Inc., Warrenton, VA, USA) was used to perform general linear model analysis (proc.glm routine).

Effect of nicosulfuron on control and aboveground biomass of Johnsongrass. The control of Johnsongrass at the four leaf stage with reduced rates of nicosulfuron was biotype dependent (Table 1). Johnsongrass biomass of the Santa Rosa, General Pico, and Río Cuarto biotypes was 35% of the untreated control following nicosulfuron at 0.125X, while the control of biotypes from Rojas and Paraná was approximately 65% of the untreated control. Control of La Plata and Laboulaye was intermediate (Table 1). At 0.25X, a similar trend was observed (Table 1).

Nicosulfuron at 0.5X provided 96% of humid biotype's control, while the control for Santa Rosa, General Pico, and Río Cuarto biotypes was significantly lower. At the same rate, the control of Laboulaye biotype was 89% and differed significantly with respect to subhumid biotypes. In addition, Laboulaye biotype showed significant difference in percent of control compared to the most sensitive group from the humid region (Rojas and Paraná biotypes) (Table 1). No further significant ($P < 0.05$) fresh aboveground biomass reduction was observed above 0.5X for La Plata, Rojas, Paraná, and Laboulaye and above 0.75X for Santa Rosa, General Pico, and Río Cuarto. Plants from these three biotypes were less sensitive to nicosulfuron than plants originating from the La Plata, Rojas, Paraná, and Laboulaye biotypes for all the nicosulfuron rates evaluated (Table 1).

Table 1. Control percentage of the seven Johnsongrass biotypes compared with fresh weight of untreated plants at nicosulfuron rates (X = labeled rate). Values designated by the same letter do not differ significantly ($P < 0.05$) within each nicosulfuron rate.

Population	**1.5X**	**1.0X**	**0.75X**	**0.5X**	**0.25X**	**0.125X**
Santa Rosa	84.3 a	84.3 a	80.3 a	72.5 ab	57.8 a	34.3 a
General Pico	87.1 a	85.2 a	78.8 a	69.5 a	55.7 a	34.5 a
Río Cuarto	85.8 a	85.8 a	82.0 a	76.4 b	62.2 a	37.7 a
Laboulaye	95.9 b	95.0 b	93.7 b	89.2 c	75.8 b	44.6 b
La Plata	99.8 b	99.8 b	99.8 b	94.5 cd	78.9 b	51.5 c
Rojas	99.8 b	99.8 b	99.8 b	96.6 d	87.1 c	64.1 d
Paraná	99.8 b	99.8 b	99.8 b	97.7 d	88.8 c	66.4 d

Comparison of regression coefficients revealed that the biotypes responded differently to reduced rates of nicosulfuron (Fig. 2). The lower fresh weight asymptote ($a1$), the difference between upper and lower weight asymptote ($a2$), and the rate associated with lower weight asymptote ($a3$) of aboveground biomass curves for Santa Rosa, General Pico, and Río Cuarto biotypes were different from those obtained in La Plata, Rojas, Paraná, and Laboulaye biotypes (Table 2, Fig. 2). Biotype from Laboulaye showed different regression coefficient from the other two groups, so three groups can be characterized. An adequate fit was observed in all biotypes with R^2 ranging from 0.85 to 0.96 (Table 2).

Table 2. Nonlinear regression coefficients for nicosulfuron rate response models from seven Johnsongrass biotype. Means in each column followed by same letter not significantly different according to Fisher's protected LSD (0.05) test. Values of lower fresh weight asymptote (*a1*), difference between upper and lower weight asymptote (*a2*) and rate associated with lower weight asymptote (*a3*) are shown.

Biotype	***a1*** (g/pl)	***a2*** (g/pl)	***a3*** (1/X)	**R^2**
Santa Rosa	16.1 a	86.4 a	3.31 a	0.87
General Pico	14.4 a	94.5 a	3.18 a	0.93
Río Cuarto	15.2 a	91.3 a	3.87 a	0.85
La Plata	0.14 b	127.2 b	7.12 b	0.92
Rojas	0.19 b	147.8 b	7.02 b	0.96
Parana	0.21 b	133.4 b	8.66 b	0.91
Laboulaye	4.51 c	107.5 c	4.62 c	0.94

Effect nicosulfuron on Johnsongrass regrowth and seed production. The fresh rhizome weight (g/pl), total rhizome length (cm), number of rhizome nodes, and the number of seed per plant after a growth period of 16 weeks (20 WAT, 5 April 2005 and 15 April 2006) were recorded. Fresh rhizome weight, total rhizome length, and the number of seed per plant (Figs. 3, 4, and 6) of the humid region bioytpes were significantly higher than those of the subhumid region.

The number of nodes produced by rhizomes did not differ significantly between biotypes (Fig. 5). The average fresh rhizome weight of untreated plants varied from 460.1 to 485.7 g in subhumid biotypes while humid biotypes varied from 555.3 to 594 g (Fig. 3). Average total rhizome length varied from 795 to 897 cm/pl in subhumid biotypes while in biotypes from humid regions varied from 997.3 to 1007.2 cm/pl (Fig. 4). All four humid biotypes produced more seed per plant than the three subhumid ones (Fig. 6).

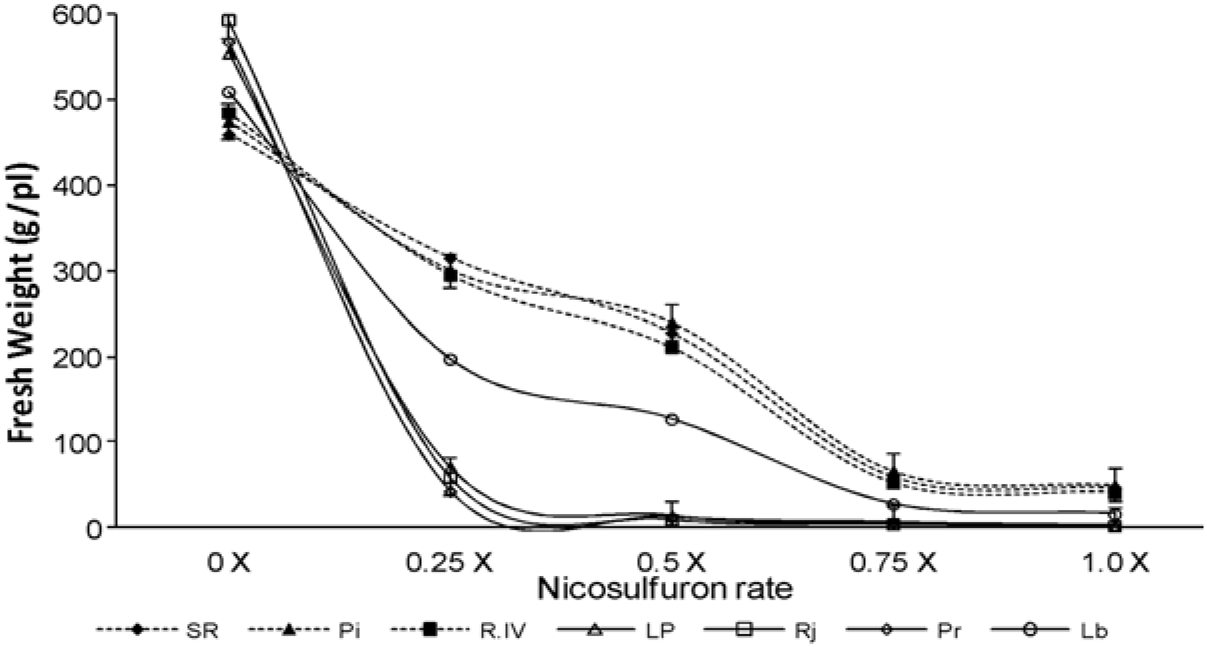

Fig. 3. Fresh rhizome biomass of the seven Johnsongrass biotypes from Santa Rosa (SR), General Pico (Pi), Río Cuarto (R.IV), La Plata (LP), Rojas (Rj), Paraná (Pr), and Laboulaye (Lb) at reduced nicosulfuron rates (X = labeled rates) after a growth period of 16 weeks (20 weeks after nicosulfuron application). Vertical bars are ± standard deviation.

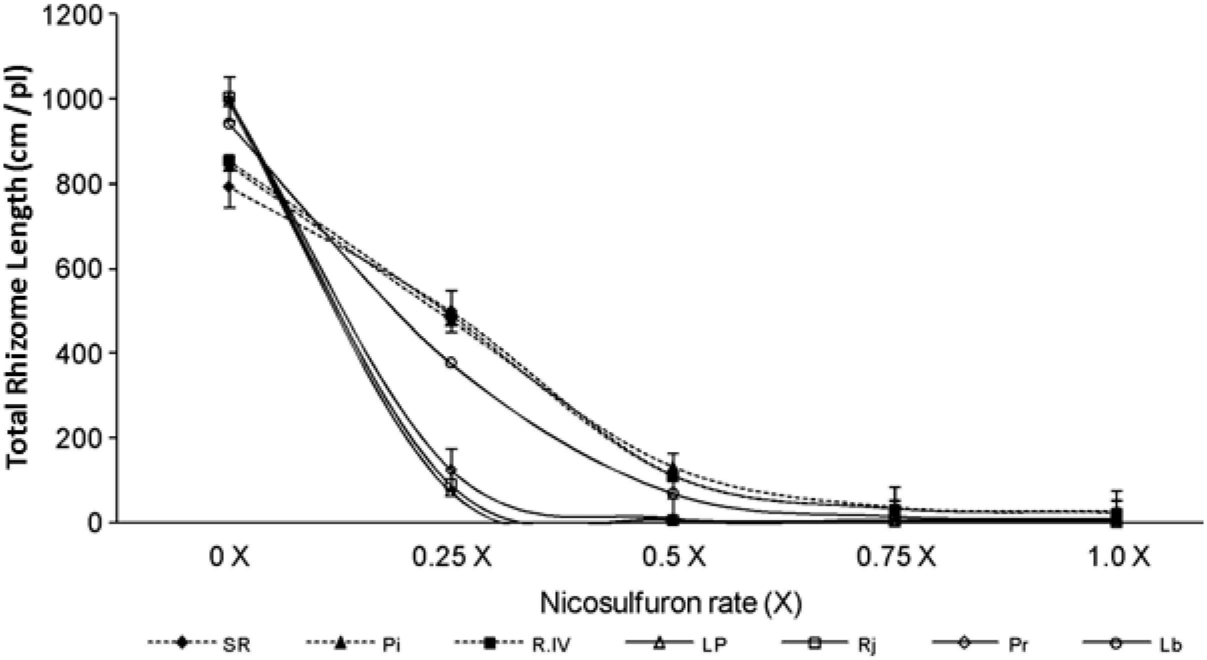

Fig. 4. Total rhizome length of the seven Johnsongrass biotypes from Santa Rosa (SR), General Pico (Pi), Río Cuarto (R.IV), La Plata (LP), Rojas (Rj), Paraná (Pr), and Laboulaye (Lb) at reduced nicosulfuron rates (X = labeled rate) after a growth period of 16 weeks (20 weeks after nicosulfuron application). Vertical bars are ± standard deviation.

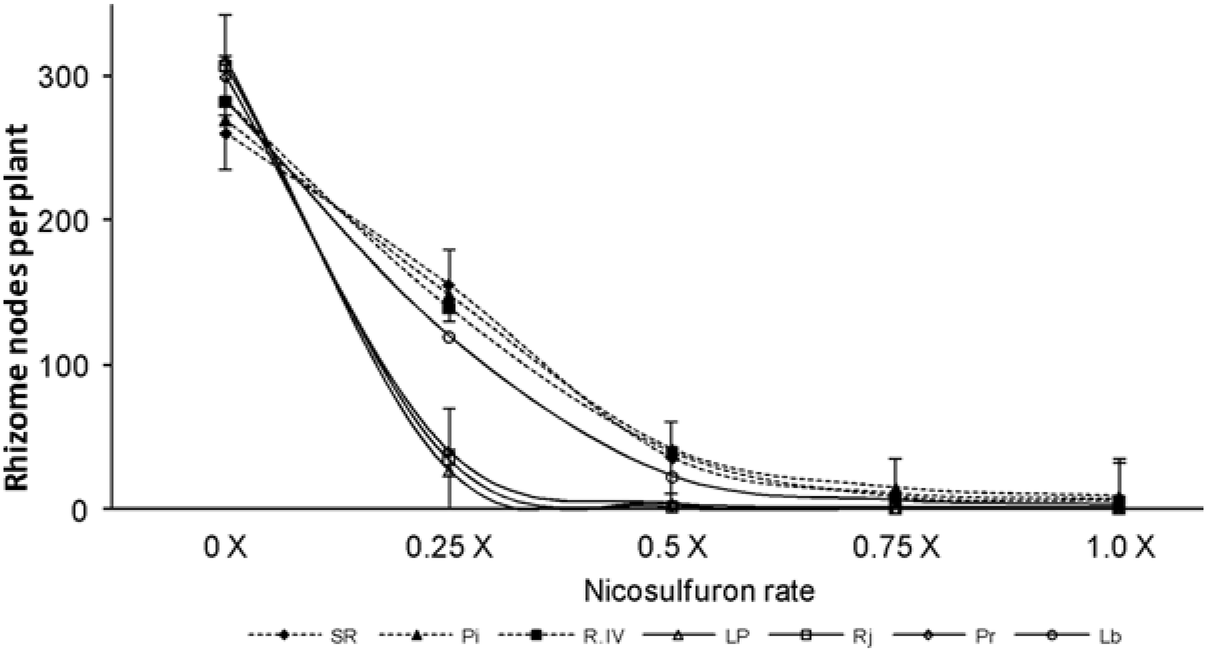

Fig. 5. Number of rhizome nodes of the seven Johnsongrass biotypes from Santa Rosa (SR), General Pico (Pi), Río Cuarto (R.IV), La Plata (LP), Rojas (Rj), Paraná (Pr), and Laboulaye (Lb) at reduced nicosulfuron rates (X = labeled rate) after a growth period of 16 weeks (20 weeks after nicosulfuron application). Vertical bars are ± standard deviation.

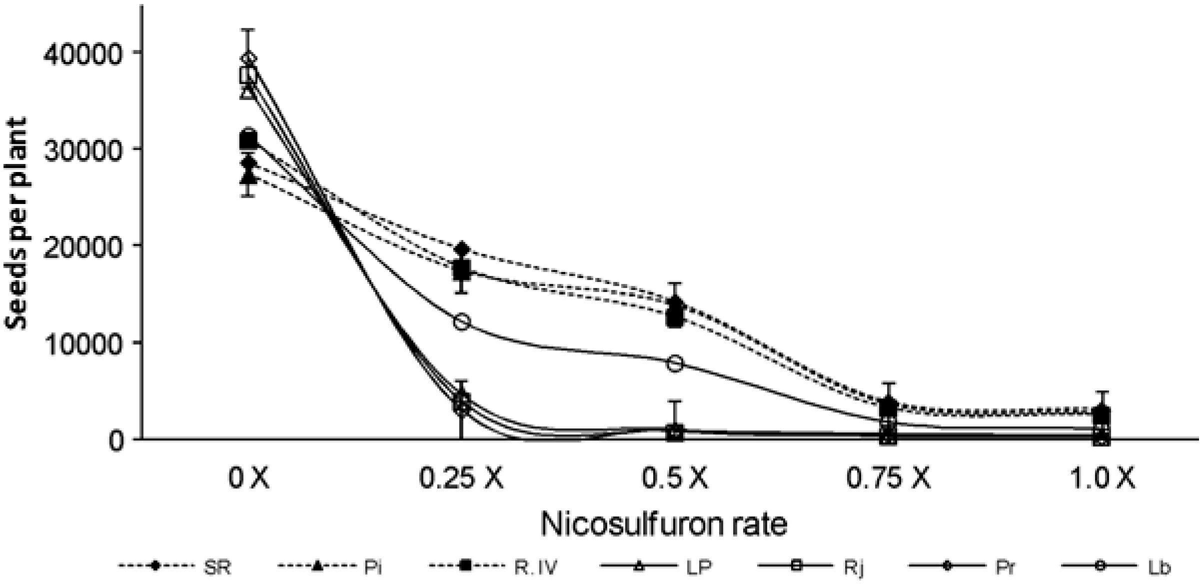

Fig. 6. Number of seeds of Johnsongrass biotypes from Santa Rosa (SR), General Pico (Pi), Río Cuarto (R.IV), La Plata (LP), Rojas (Rj), Paraná (Pr), and Laboulaye (Lb) at reduced nicosulfuron rates (X = labeled rate) after a growth period of 16 weeks (20 weeks after nicosulfuron application). Vertical bars are ± standard deviation.

No significant difference in fresh rhizome weight and seed number between biotypes at 1.0X and 0.75X herbicide rates were observed (Figs. 3 and 6). Significant difference ($P < 0.05$) appeared between humid and subhumid biotypes when 0.5X and 0.25X herbicide rates were considered. The fresh rhizome weight means were 226.8 g and 304.3 g for subhumid biotypes, 12.7 g and 58.2 for humid biotypes at 0.5X and 0.25X, respectively. The average production of seeds was 13,580 and 18,240 for subhumid biotypes and 845 and 3,845 for humid biotypes seeds per plant at 0.5X and 0.25X respectively. Laboulaye biotype showed an intermediate trend between these groups (Figs. 3 and 6). Only the total rhizome length and the number of rhizome nodes per plant obtained at 0.25X herbicide rate differ significantly ($P < 0.05$) between both biotype groups (Figs. 4 and 5).

Implications of Using Reduced Rates of Nicosulfuron

Previous studies have established that reduced rates of nicosulfuron controlled rhizome Johnsongrass effectively when applied at early growth stages (6,15). In the current study, reduced nicosulfuron rates provided adequate Johnsongrass control when applied at the 3-4-leaf stage, but the results varied according to the biotype considered. Biotypes from subhumid regions were significantly less susceptible than biotypes from humid regions to nicosulfuron from the 0.125X to 0.75X rate. The border location between the humid and subhumid regions of the Laboulaye biotype could be the reason for the intermediate trends observed in the current work (Fig. 1).

This study showed that three subhumid biotypes were less sensitive to nicosulfuron and substantial differences in fresh rhizome weight, total rhizome length and number of rhizomes nodes in 16-week-old plants (20 WAT) were observed. Additionally, nicosulfuron applied at 0.5X and below tended to increase these differences in regrowth. Previous studies have shown no Johnsongrass regrowth after nicosulfuron application under different experimental conditions. Johnson et al. (9) obtained no Johnsongrass regrowth 3 WAT applying nicosulfuron at the labeled rate, but the authors stated that regrowth would have occurred if they had allowed the weed to remain longer in the experiment as in the current work. Moreover, Eleftherohorinos and Kotoula-Syka (6) have indicated that no regrowth occurred within 8 to 12 WAT when reduced nicosulfuron rates were used but only one Johnsongrass biotype was tested so no information about different regrowth rates can be obtained as in the current study. Johnsongrass of subhumid biotypes exposed to low rates of nicosulfuron (mainly 0.5X and 0.25X) could result in both a soil seed bank (16) and rhizome biotype increase. The current study shows that the use of low rates of nicosulfuron is not an effective Johnsongrass management strategy and that control was biotype related. A minimum of a 0.75X rate was required to control either Johnsongrass biotype. In addition, the selection induced at lower herbicide dose (most plants killed but some survivors) selects for all increased resistance-endowing genes (13). Considering the growth parameters evaluated, the two class of Argentinean biotype showed a significant difference in the sensitivity to nicosulfuron at reduced rates. According to the results of Johnsongrass regrowth recorded, the use of rates below 0.75X of nicosulfuron labeled rate must be avoided in these environments.

From the data obtained in the current study it was determined that an adequate knowledge of Johnsongrass biotype performance will be required to design an IWM program, but that use of nicosulfuron at lower rates is not a viable solution. Moreover, the trends obtained preclude the extrapolation of the use of herbicide reduced rates from subhumid to humid region. In order to minimize Johnsongrass regrowth, the long-term effects of this control strategy should be investigated.

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