Weed Technology 2012 26:77–82

Control of Morningglories (*Ipomoea* spp.) in Sugarcane (*Saccharum* spp.)

Makhan Singh Bhullar, U. S. Walia, Surjit Singh, Megh Singh, and Amit J. Jhala*

Morningglories are summer annual or perennial dicots, and are troublesome weeds in sugarcane cultivated in northern India. If not controlled, they may compete with sugarcane, interfere in the harvest operation, and reduce yields. Managing morningglories in sugarcane continues to be a serious challenge for sugarcane growers. Field experiments were conducted during the 3-yr period from 2007 to 2009 to evaluate herbicides applied PRE and POST for control of morningglories in sugarcane. The herbicides applied PRE included diuron, metribuzin, and atrazine at 1.6, 1.4, and 1.0 kg ai ha^{-1}, respectively, applied alone or followed by 2,4-D amine salt (0.58 or 1.16 kg ae ha^{-1}) or 2,4-D sodium salt (0.8 or 1.6 kg ae ha^{-1}) applied POST. Herbicides applied PRE controlled morningglories $\leq$ 87% at 15 d after treatment (DAT); however, control reduced to $\leq$ 56% at 90 DAT. Control improved when herbicides applied PRE were followed by POST application of 2,4-D amine or sodium salt. For example, diuron applied PRE followed by 2,4-D amine salt applied POST at any rate provided 100% control of morningglories at 15 and 30 DAT. At 90 d after POST application, control ranged from 68 to 82% with the PRE followed by POST herbicides, compared to 0% control when metribuzin or atrazine were applied PRE alone. The density and biomass of morningglories was also reduced to zero in treatments that included 2,4-D amine salt. The number of millable canes, cane height, and single cane weight was superior in PRE followed by POST herbicide treatments compared to herbicides applied PRE alone. Maximum cane yield was recorded for the treatments that included 2,4-D amine or sodium salt compared to only PRE treatments, and it was usually comparable with the nontreated weed-free control. It is concluded that a combination of PRE and POST herbicides were effective for control of morningglories; however, more research is required to evaluate other herbicides and their tank mix partners for control of morningglories in sugarcane.

Nomenclature: Japanese morningglory, *Ipomoea nil* (L.) Roth.; obscure morningglory, *Ipomoea obscura* L. Ker Gawl.; sugarcane, Saccharum spp.

Key words: Cane yield, crop–weed competition, herbicides, millable cane, percentage of control.

Las *Ipomoea* son plantas dicotiledóneas perennes o anuales de verano y constituyen un problema en el cultivo de la caña de azúcar en el norte de la India. Si no se controlan pueden competir con la caña, interferir en la cosecha y reducir los rendimientos. El manejo de las I*pomoea* en la caña de azúcar continúa siendo un reto serio para los productores. Experimentos de campo fueron realizados durante un período de tres años (de 2007 a 2009), para evaluar herbicidas aplicados PRE y POST para el control de *Ipomoea* en caña de azúcar. Los herbicidas aplicados PRE incluyeron diuron, metribuzin y atrazina a 1.6, 1.4, y 1.0 kg ia ha^{-1}, respectivamente aplicados solos o seguidos por 2,4-D sal amina (0.58 o 1.16 kg ea ha^{-1}) o 2,4-D sal sódica (0.8 o 1.6 kg ea ha^{-1}), aplicados POST. Los herbicidas aplicados PRE controlaron las *Ipomoea* $\leq$ 87% a 15 días después del tratamiento (DAT); sin embargo, el control disminuyó a $\leq$ 56% a 90 DAT. El control mejoró cuando los herbicidas aplicados PRE fueron seguidos por aplicaciones POST de 2,4-D sal amina o 2,4-D sal sódica. Por ejemplo, diuron aplicado PRE seguido por 2,4-D sal amina aplicado POST a cualquier dosis, proporcionó 100% de control de las *Ipomoea* a 15 y 30 DAT. A 90 días después de la aplicación POST, el control varió de 68 a 82% con PRE seguido por los herbicidas POST, en comparación con 0% de control cuando metribuzin o atrazina fueron aplicados solos en PRE. La densidad y biomasa de las *Ipomoea* también se redujeron a cero en tratamientos que incluyeron 2,4-D sal amina. El número de cañas utilizables, la altura de caña, y el peso de una sola caña fueron superiores en PRE seguidos por tratamientos con herbicidas POST, comparado con solo herbicidas en PRE. El rendimiento máximo de caña fue registrado para los tratamientos que incluyeron 2,4-D amina o sal sódica comparado a únicamente tratamientos PRE, y fue usualmente comparable con el testigo no tratado libre de maleza. Se concluye que la combinación de herbicidas PRE y POST fue efectiva para el control de las *Ipomoea*; sin embargo, se requiere de más investigación para evaluar otros herbicidas y sus mezclas en tanque, para el control de las *Ipomoea* en cultivos de caña de azúcar.

India is the second largest producer of sugarcane (next to Brazil), contributing nearly 15% of the total sugarcane production in the world (FAO 2008). In 2010, sugarcane was grown on $>$ 4.4 million hectares with the production of about 292 million tonnes in India (Anonymous 2011a). India is the largest consumer of sugar, including traditional cane sugar sweeteners and many other products equivalent to 26 million tonnes of raw value. Sugarcane is being raised as a perennial cash crop with two to three annual harvests in northern India (Jeyaraman et al. 2002). Sugarcane grows well in medium to heavy well-drained soils with pH 7.8 to 8.5 and with high organic matter content. Heat, relative humidity, and light intensity play an important role in sugarcane germination, tillering, vegetative growth, and maturity (Anonymous 2011b).

Weed management is an important component of sugarcane production practices (Jeyaraman et al. 2002; Singh

DOI: 10.1614/WT-D-11-00112.1

* First, second, and third authors: Agronomist, Senior Agronomist, and Senior Extension Specialist, respectively, Department of Agronomy, Punjab Agricultural University, Ludhiana 141004, Punjab, India; fourth and fifth authors: Professor and Postdoctoral Research Associate, Weed Research Program, Citrus Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida, 700 Experiment Station Road, Lake Alfred, FL 33850-2299. Corresponding author's E-mail: amit@ufl.edu

et al. 2001). In recent years, two new broadleaf weeds, Japanese morningglory and obscure morningglory have been found in sugarcane fields in northern India (Marimuthu et al. 2002). These two *Ipomoea* spp. are common and problematic in the Punjab province of India, infesting not only sugarcane fields but also cotton (*Gossypium hirsutum* L.), maize (*Zea mays* L.), soybean (*Glycine max* L.), and vegetable crop fields.

With over 500 species, *Ipomoea* is the largest genus in the flowering plant family Convolvulaceae (Willis 1966). The *Ipomoea* spp. are problem weeds in many other countries. For example, in the southern United States, ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], pitted morningglory (*Ipomoea lacunose* L.), palmleaf morningglory (*Ipomoea wrightii* Gray), and smallflower morningglory (*Jacquemontia tamnifolia* L.) are listed among the 10 most troublesome weeds (Webster 2005). In the continental United States, sugarcane is primarily grown in Florida, Louisiana, and Texas (Anonymous 2005). Red morningglory (*Ipomoea coccinea* L.) is one of the most troublesome broadleaf weeds in sugarcane cultivation in Louisiana (Webster 2000).

Ipomoea spp. can germinate over a wide range of temperatures (Egley 1990; Gomes et al. 1978). Along with the planting operation of sugarcane, *Ipomoea* spp. seeds are buried under the soil and exhibit low germination. They return to, or close to, the soil surface and germinate profusely when the growers practice earthing-up tillage operations in the month of June before onset of monsoon season. Mixing of soil through tillage also scarifies *Ipomoea* spp. seeds, increasing germination, and soil temperature also regulates germination of seeds. The sugarcane crop at that time is generally at the tillering stage. The emergence periodicity of *Ipomoea* spp. is the most prevalent after the final layby cultivation, and it can thrive underneath the sugarcane canopy (Millhollon 1988; Thakar and Singh 1954).

Although the critical period of weed competition in sugarcane is 90 d after planting (Jeyaraman et al. 2002; Rangaiah et al. 1988), the twining weeds pose a further problem by their nature of growth and by occupying the top plane of the cane, thus extending the critical period. These twining weeds not only compete with the growing crop but also create physical hindrance during harvesting (Griffin et al. 2000). In addition to loss from crop–weed competition, *Ipomoea* spp. climb and wrap sugarcane stalks, causing lodging that reduces both the number of millable stalks and sugarcane yields (Marimuthu et al. 2002). If left uncontrolled, red morningglory reduced cane yield up to 30% (Jones and Griffin 2009; Millhollon 1988). Similarly, ivyleaf morningglory reduced sugarcane yield 20 to 25% due to physical hindrance and by reducing harvest efficiency (Thakur and Singh 1954).

Sugarcane takes about 30 to 45 d for sprouting and approximately 4 mo to form a canopy sufficient to cover the soil. This leads to heavy infestation of *Ipomoea* spp., which can reduce sugarcane productivity. Weed control programs in sugarcane are based on the use of PRE herbicides for control of emerging annual grasses and broadleaf weeds, and POST herbicides for control of weeds, including some perennial weeds emerging later in the season (Odero and Dusky 2011). Glyphosate is relatively less effective on control of *Ipomoea* spp. compared to many other common weeds (Jordan et al. 1997). Some herbicides applied PRE—including atrazine, metribuzin, and diuron—are registered for weed control in sugarcane in Punjab; however, atrazine, being the least expensive, is the most commonly used PRE herbicide in sugarcane cultivation. The majority of PRE herbicides typically control weeds for 2 to 3 mo in sugarcane. Millhollon (1988) observed 84 to 93% control of red morningglory at 20 DAT with atrazine applied PRE at 1.8 kg ha^{-1}. However, PRE herbicides do not generally provide season-long weed control in sugarcane.

The timing of herbicide application is also an important aspect in the sugarcane weed management program. PRE herbicides are applied at the time of planting in spring (February to March) and POST herbicides are applied in April or May. A previous study reported that late application of atrazine (even at a high rate: 2.24 kg ha^{-1}) in July controlled red morningglory no more than 39% and sugarcane yield was reduced by 39% (Jones and Griffin 2009). Some reports also revealed that an application of atrazine in early- to mid-May was not effective for control of red morningglory (Griffin et al. 2000). Diuron applied PRE at 1.68 kg ha^{-1} controlled red morningglory up to 53%, whereas increasing the diuron rate to 2.24 kg ha^{-1} increased control up to 76% (Millhollon 1988). Higher rates of diuron at 3.36 kg ha^{-1} controlled red morningglory 83 to 99% in the first year, but only 73% in the second year (Viator et al. 2002). Control of red morningglory with metribuzin applied at 1.12 kg ha^{-1} was 96 and 60% in the first and second years, respectively; the difference in control between the 2 yr was attributed to timing of an activating rainfall, soil pH, and organic matter (Viator et al. 2002). Therefore, control of *Ipomoea* spp. with soil-applied herbicide is inconsistent and often inadequate (Vencill et al. 1995) and requires POST herbicides.

The onset of the rainy season at the end of June or early July and warm soil temperature proves conducive for rapid herbicide degradation, which often results in late-season weed infestations in sugarcane. Therefore, herbicides applied POST are required for late-season weed control. A previous study indicating that an application of 2,4-D was highly effective for control of *Ipomoea* spp.; however, the response was variable with application rates and size (Griffin et al. 2000). Jones and Griffin (2009) reported that when environmental conditions are conducive to prolific growth of *Ipomoea* spp. and they climb sugarcane stalks, 2,4-D still remains the most effective treatment. Therefore, PRE herbicide followed by POST is the best combination for adequate control of *Ipomoea* spp. in sugarcane (Kathiresan et al. 2004). A tank mix of herbicides is also a good option for hard-to-control weeds such as *Ipomoea* spp. Researchers have evaluated several tank mix partners with glyphosate for control of *Ipomoea* spp. in glyphosate-resistant soybean (Ateh and Harvey 1999); however, this option is only suitable for glyphosate-resistant crops. Crop injury is an additional concern with herbicides applied POST. York et al. (1991) reported early season injury to soybean but no yield reduction when 2,4-DB at 35 g ha^{-1} was mixed with acifluorfen, chlorimuron, or imazethapyr. Barker et al. (1984) reported yield reductions when 2,4-DB at 35 to 70 g ha^{-1} was applied to soybean.

Limited information is available on chemical control of *Ipomoea* spp. in sugarcane in northern India. The objectives of this investigation were (1) to evaluate PRE herbicides applied alone or followed by POST herbicides for control of *Ipomoea* spp. in sugarcane, (2) to determine the effects of herbicides on yield and yield attributes of sugarcane, and (3) to evaluate if selected PRE and POST herbicides have any phytotoxic effects on sugarcane.

Materials and Methods

Field experiments were conducted at the Agronomy Research Station, Punjab Agricultural University, Ludhiana (30°56′N, 75°52′E), India during the 2007 to 2008, 2008 to 2009, and 2009 to 2010 growing seasons. The soil was sandy loam with pH 8.0, organic carbon 0.29%, N 200 kg ha^{-1}, P 21.2 kg ha^{-1}, K 235 kg ha^{-1}, and electrical conductivity (EC) 0.20 dS m^{-1}. Each year, the experiment was conducted in a randomized complete block design with four replications. A sugarcane cultivar 'CoJ 88' with high sugar content was planted with 50,000 three-budded setts ha^{-1} in furrows spaced at 75 cm. The plot size was 6.0 m by 5.0 m. The crop was planted on March 26, 2007, March 6, 2008, and March 10, 2009. The crop was fertilized with 75 kg N and 16 kg P ha^{-1}. Total quantity of P and one-third N was applied at the time of planting in furrows below the cane setts and the rest of N was applied in two equal splits when crop was at the tillering stage.

To simulate *Ipomoea* spp. infestations, a mixture of seeds of two *Ipomoea* spp. (Japanese and obscure morningglory) was manually dribbled at the rate of about 100 seeds $plot^{-1}$ (3 to 4 seeds $hill^{-1}$) at a depth of 2 to 3 cm. The seeds of *Ipomoea* spp. were seeded in the field on the day of sugarcane planting. The herbicides applied PRE included diuron (Klass herbicide, Bayer Crop Science Ltd., Bayer House, Central Avenue, Hiranandani Gardens, Powai, Mumbai 400 076, India) at 1.6 kg ai ha^{-1}, metribuzin (Sencor herbicide, Bayer Crop Science Ltd.) at 1.4 kg ai ha^{-1}, and atrazine (Atrataf herbicide, Rallis India Limited, Apeejay House, 3 Dinshaw Vachha Road, Churchgate, Mumbai 400 020, India) at 1.0 kg ai ha^{-1}. The PRE herbicides were applied within 2 d of seeding *Ipomoea* spp. with a knapsack sprayer calibrated to apply 500 L ha^{-1} with flat fan nozzles. The herbicides applied POST included 2,4-D amine salt (Weedor herbicide, Crystal Phosphate Limited, V & PO, Nathupur, Dist., Sonepat 131 029, Haryana, India) at 0.54 or 1.08 kg ae ha^{-1}, 2,4-D sodium salt (Dhanuka Weedmar 80 herbicide, Dhanuka Agritech Ltd., Daultabad Road, Gurgaon 122 001, Haryana, India) at 0.8 or 1.6 kg ae ha^{-1}. The POST treatments were sprayed on June 30, 2007, July 9, 2008, and July 4, 2009, when the *Ipomoea* spp. plants were at the three- to five-leaf stage. A nontreated weedy control and a nontreated weed-free control were included for comparison. Nontreated weed-free plots were maintained weed-free by hand-weeding throughout the growing season.

The *Ipomoea* spp. densities were assessed during the growing season within 0.5-m^2 quadrats (3 quadrats $plot^{-1}$), at 30 d of PRE and POST herbicide applications. In addition, visual control ratings of *Ipomoea* spp. were determined at 15, 30, 60, and 90 DAT of PRE and POST herbicides based on a 0 to 100% scale, with 0% being no control and 100% being complete control of *Ipomoea* spp. Biomass of *Ipomoea* spp. was measured a month after the POST herbicide treatments on July 29, 2007, August 10, 2008, and August 5, 2009. *Ipomoea* spp. that survived were cut at the stem base close to the soil surface from a randomly selected 0.5-m^{-2} quadrat (2 quadrats $plot^{-1}$), placed in paper bags, dried in an oven for 72 h at 60 C; the biomass was then recorded. Sugarcane stalk population was determined by counting all millable canes per plot. Millable cane length was determined by measuring the height to the terminal node of 10 stalks $plot^{-1}$. Before harvesting, samples of 10 randomly selected stalks from each plot were weighed to determine the average single cane weight. The crop was harvested manually on January 17, 2008, January 16, 2009, and January 15, 2010, and the data of cane yield per plot were recorded.

Statistical Analysis. Data were subjected to ANOVA using statistical analysis software (SAS Institute 2009). Normality, homogeneity of variance, and interactions of treatments and years were tested. In this experiment, year by treatment interactions were nonsignificant; therefore, the data from 3 yr were pooled and the combined data were presented. The data of *Ipomoea* spp. density, biomass, and visual control ratings were arc-sine transformed prior to analysis; however, nontransformed data are presented with mean separation based on transformed data. Where the ANOVA indicated that treatment effects were significant, means were separated at $P \leq 0.05$ and adjusted with Fisher's Protected LSD test.

Results and Discussion

Sugarcane Injury. No significant sugarcane injury was observed in any herbicide treatment in any year, which indicated that all evaluated herbicides were safe for use in sugarcane (data not shown). All herbicides were applied as per the labeled guidelines; therefore, the absence of sustained injury was expected.

***Ipomoea* spp. Control.** The experimental site was infested with two species of *Ipomoea*, Japanese morningglory and obscure morningglory; however, all data were collected as the total of two species and presented as *Ipomoea* spp. because the response of both the species to herbicide treatments was similar. All PRE-applied herbicides were effective for controlling *Ipomoea* spp. compared to nontreated weedy control at 15, 30, 60, and 90 DAT (Table 1). However, no PRE-applied herbicide was comparable to the nontreated weed-free control. Diuron and atrazine applied PRE at 1.6 and 1 kg ha^{-1}, respectively, controlled *Ipomoea* spp. in the range of 84 to 87% at 15 DAT, but control with metribuzin at 1.4 kg ha^{-1} was poor ($\leq$ 32%). In contrast, a 2-yr study by Viator et al. (2002) reported 60 to 96% control of red morningglory with metribuzin applied at 1.12 kg ha^{-1}; the difference in control between years was attributed to timing of activating rainfall, soil pH, and organic matter. Millhollon (1988) observed 84 to 93% control of red morningglory with atrazine applied PRE at 1.8 kg ha^{-1} or applied early POST at 2.23 kg ha^{-1}.

Table 1. Effects of herbicide treatments on control of *Ipomoea* spp. at 15, 30, 60, and 90 DAT in sugarcane in 2007, 2008, and 2009.[a]

			After PRE[c]				After POST[c]			
Treatment[b] PRE fb[b] POST	PRE	POST	15 DAT	30 DAT	60 DAT	90 DAT	15 DAT	30 DAT	60 DAT	90 DAT
	—Rate kg ae or ai ha^{-1} –		%							
Nontreated weedy	-	-	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a
Nontreated weed-free[d]	-	-	100 d	100 d	100 d	100 d	100 c	100 c	100 c	100 d
Diuron fb 2,4-D amine salt	1.6	0.58	87 b	75 b	60 b	56 b	100 c	100 c	89 c	78 c
Diuron fb 2,4-D amine salt	1.6	1.16	85 b	72 b	50 b	30 c	100 c	100 c	85 c	82 c
Diuron fb 2,4-D sodium salt	1.6	0.8	84 b	68 b	45 b	38 c	78 b	94 b	76 b	70 bc
Diuron fb 2,4-D sodium salt	1.6	1.6	85 b	74 b	35 c	32 c	90 bc	95 bc	87 bc	78 c
Metribuzin	1.4	-	29 c	20 c	20 c	8 a	0 a	0 a	0 a	0 a
Metribuzin fb 2,4-D amine salt	1.4	0.58	32 c	25 c	15 c	3 a	99 c	91 b	88 c	80 c
Atrazine	1.0	-	86 b	80 b	40 b	30 c	0 a	0 a	0 a	0 a
Atratize fb 2,4-D amine salt	1.0	0.58	84 b	78 b	38 b	35 c	85 bc	89 b	83 b	68 bc

[a] There was no year by treatment interaction, therefore the data from 3 yr were pooled and combined data are presented.

[b] Abbreviations: DAT, days after treatment; fb, followed by.

[c] Means within columns without letter(s) in common are significantly different according to Fisher's Protected LSD test ($P < 0.05$).

[d] Nontreated weed-free control plots were maintained weed-free by hand-weeding throughout the growing season.

Control of *Ipomoea* spp. decreased at and beyond 30 DAT (Table 1). For example, diuron and atrazine applied PRE controlled *Ipomoea* spp. in the range of 30 to 56% and 30 to 35%, respectively, whereas control with metribuzin was similar to the the nontreated weedy control at 90 DAT. Similarly, experiments conducted in Louisiana revealed that red morningglory control was not sustained when atrazine was applied at layby in early- to mid-May (Griffin et al. 2000). Viator et al. (2002) reported that atrazine, diuron, and metribuzin applied at 1.68, 3.36, and 1.12 kg ha^{-1}, respectively, controlled red morningglory no more than 83% at 45 DAT. A late application of atrazine at 2.24 kg ha^{-1} in July controlled red morningglory no more than 39% (Jones and Griffin 2009). A preliminary study was conducted to evaluate activity of diuron or metribuzin applied POST, but these treatments were not successful for control of *Ipomoea* spp.; instead, there was a significant injury to sugarcane plants (M. S. Bhullar, unpublished data). Millhollon (1988) reported that PRE application of diuron at 1.68, 2.24, and 3.36 kg ha^{-1} resulted in 53, 76, and up to 99% control, respectively, of red morningglory.

A follow-up POST application of herbicides provided effective control of the *Ipomoea* spp. For example, when diuron was followed by 2,4-D amine salt, 100% control of *Ipomoea* spp. was observed at 15 and 30 DAT (Table 1). Similarly, 2,4-D sodium salt applied at 1.6 kg ha^{-1} was equally effective, but control was reduced to 78% when the lower rate (0.8 kg ha^{-1}) was applied. Metribuzin applied PRE was not effective for control of *Ipomoea* spp.; however, when it was followed by 2,4-D amine salt, 99 and 91% control was observed at 15 and 30 DAT, respectively. Similarly, atrazine applied alone was not effective, but when it was followed by 2,4-D amine salt, good control was observed at 15 and 30 DAT. In a similar study, Kathiresan et al. (2004) reported excellent control of *Ipomoea sepiaria* with atrazine applied PRE followed by 2,4-D sodium salt applied POST at 1 kg ha^{-1}.

Control of *Ipomoea* spp. diminished at 60 and 90 DAT; however, PRE followed by POST herbicide treatments were still more effective than a PRE-only herbicide application. A previous study also reported that control of *Ipomoea* spp. by soil-applied herbicide is not adequate (Vencill et al. 1995) and herbicides applied POST are generally more effective (Elmore et al. 1990). Sugarcane growers frequently use POST-applied herbicides in conjunction with PRE herbicides for controlling *Ipomoea* spp. (Reynolds et al. 1995).

Ipomoea spp. density was affected by herbicide treatments (Table 2). All PRE-applied herbicides reduced *Ipomoea* spp. density compared to the nontreated weedy control at 30 DAT. Atrazine reduced *Ipomoea* spp. density to $\leq$ 1.3 plants m^{-2} compared to diuron (1.2 to 2.5 plants m^{-2}) and metribuzin (3.8 to 4.2 plants m^{-2}), all of which were less than the 6.5 plants m^{-2} in the nontreated weedy control (Table 2). The density of *Ipomoea* spp. was further reduced after POST herbicide treatments. For example, diuron and metribuzine applied PRE followed by 2,4-D amine salt applied POST at both rates reduced density of *Ipomoea* spp. to as low as 0 plants m^{-2}. Compared to other herbicide treatments, metribuzin and atrazine applied PRE alone had the highest density of *Ipomoea* spp. (4.5 and 2.1 plants m^{-2}, respectively). Herbicides applied PRE are effective for controlling grass and broadleaf weeds in sugarcane, but in most cases they do not provide long-term weed control and additional weed control treatments are required (Griffin and Judice 2009; Richard and Dalley 2006). The application of atrazine has been a common practice for many years among sugarcane producers in the Punjab province. Therefore, poor control of *Ipomoea* spp. with atrazine might be due to the accumulation of atrazine-degrading soil microbes in response to repeated atrazine use (Ostrofsky et al. 1997; Yassir et al. 1999).

Ipomoea spp. biomass reflected results of percentage of control and density previously reported (Table 2). All herbicide treatments reduced weed biomass compared to the nontreated weedy control. Among herbicide treatments, metribuzin and atrazine applied PRE alone were not as effective in reducing biomass of *Ipomoea* spp., with 6.5 and 5.6 g m^{-2}, respectively compared to PRE followed by POST herbicide applications (0 to 3.4 g m^{-2}). Jones and Griffin (2009) reported that for atrazine to be most effective, application should be delayed until later in the growing

Table 2. Effects of herbicide treatments on *Ipomoea* spp. density, percentage of control, and biomass in sugarcane in 2007, 2008, and 2009.[a]

Treatment PRE fb[b] POST	PRE	POST	*Ipomoea* spp. density at 30 DAT[b,c] PRE	POST	Biomass[c]
	Rate kg ae or ai		plants m^{-2}		$g\ m^{-2}$
Nontreated weedy	-	-	6.5 a	0 e	11.5 a
Nontreated weed-free[d]	-	-	0 e	0 e	0 e
Diuron fb 2,4-D amine salt	1.6	0.58	1.2 d	0 e	0 e
Diuron fb 2,4-D amine salt	1.6	1.16	2.5 c	3.4 c	0 e
Diuron fb 2,4-D sodium salt	1.6	0.8	2.4 c	1.2 d	3.4 c
Diuron fb 2,4-D sodium salt	1.6	1.6	2.4 c	6.5 b	1.2 d
Metribuzin	1.4	-	4.2 b	0 e	6.5 b
Metribuzin fb 2,4-D amine salt	1.4	0.58	3.8 bc	5.6 b	0 e
Atrazine	1.0	-	1.2 d	1.1 d	5.6 b
Atratize fb 2,4-D amine salt	1.0	0.58	1.3 d	0.8 d	1.1 d

[a] There was no year by treatment interaction, therefore the data from 3 yr were pooled and combined data are presented.

[b] Abbreviations: DAT, days after treatment; fb, followed by.

[c] Means within columns without letter(s) in common are significantly different according to Fisher's Protected LSD test ($P < 0.05$).

[d] Nontreated weed-free control plots were maintained weed-free by hand-weeding throughout the growing season.

season (4 to 6 wk after layby cultivation) when both foliar and soil residual activity could occur. In this study, 2,4-D potassium salt formulation was as effective as amine salt for reducing *Ipomoea* spp. biomass. Complete control of *Ipomoea* spp. occurred when diuron or metribuzin applied PRE followed by 2,4-D amine salt. Experiments conducted by Griffin et al. (2000) also reported that 2,4-D effectively reduced biomass of *Ipomoea* spp.

Sugarcane Yield and Attributes. Higher numbers of millable canes were observed in herbicide treatments compared to the nontreated weedy control because the climbing and wrapping of the *Ipomoea* spp. to the sugarcane stalks was diminished. Similar results were observed in other studies (Millhollon 1988; Thakar and Singh 1954). There was no difference among herbicide treatments for the number of millable canes. Millable cane height was greater in PRE followed by POST herbicide treatments compared to PRE-only herbicides. These results were reflected in single cane weights (Table 3).

Sugarcane yield was variable within the different herbicide treatments. All herbicide treatments resulted in higher sugarcane yield compared to the nontreated weedy control (Table 3). Season-long *Ipomoea* spp. competition has been reported to reduce sugarcane yield by 24 to 39% (Jones and Griffin 2009; Millhollon 1988). Ivyleaf morningglory (*Ipomoea hederacea* L. Jacq.) decreased sugarcane yield 20 to 25%, mainly from physical hindrance of plant growth and decreased harvest efficiency (Thakur and Singh 1954). In the current study, sugarcane yield was greatest with POST application of 2,4-D, except when 2,4-D sodium salt was applied at the lower rate (0.8 kg ha^{-1}). Higher efficacy of 2,4-D amine salt compared to sodium salt formulation may be attributed to its higher stability and solubility in spray solution (Loos 1975). On average, treatments including POST application of 2,4-D amine increased sugarcane yields by 46 to 52% compared to nontreated weedy control. In a similar study, Kathiresan et al. (2004) reported that PRE application of atrazine followed by POST application of 2,4-D resulted in the higher cane yield. The PRE application of herbicides alone usually resulted in lower yields compared to PRE followed by POST herbicide treatments.

To conclude, this research showed that a sequential application of a PRE herbicide followed by a POST herbicide treatment provided the most effective *Ipomoea* spp. control by reducing weed density and biomass and thus reducing

Table 3. Effects of herbicide treatments on number of millable canes, cane length, single cane weight and cane yield in 2007, 2008, and 2009.[a]

Treatment PRE fb[b] POST	PRE	POST	Millable canes[c]	Cane height[c]	Single cane weight[c]	Cane yield[c]
	Rate kg ae or ai ha^{-1}		1000 ha^{-1}	cm	g	1,000 kg ha^{-1}
Nontreated weedy	-	-	62 a	136 a	640 a	49 a
Nontreated weed-free[d]	-	-	82 b	186 b	924 c	76 d
Diuron fb 2,4-D amine salt	1.6	0.58	87 b	178 b	854 c	74 d
Diuron fb 2,4-D amine salt	1.6	1.16	86 b	184 b	832 c	71 cd
Diuron fb 2,4-D sodium salt	1.6	0.8	83 b	168 b	791 b	68 bc
Diuron fb 2,4-D sodium salt	1.6	1.6	85 b	167 b	854 c	72 cd
Metribuzin	1.4	-	84 b	152 a	721 b	64 b
Metribuzin fb 2,4-D amine salt	1.4	0.58	85 b	182 b	865 c	73 d
Atrazine	1.0	-	80 b	160 a	720 b	62 b
Atratize fb 2,4-D amine salt	1.0	0.58	80 b	171 b	913 c	74 d

[a] There was no year by treatment interaction, therefore the data from 3 yr were pooled and combined data are presented.

[b] Abbreviations: fb, followed by.

[c] Means within columns without letter(s) in common are significantly different according to Fisher's Protected LSD test ($P < 0.05$).

[d] Nontreated weed free control plots were maintained wee-free by hand-weeding throughout the growing season.

crop–weed competition and resulting in increased sugarcane yields. Currently, the recommended rate of 2,4-D for control of *Ipomoea* spp. is 0.53 kg ha^{-1} for younger plants (two- to three-leaf stage) and up to 1.59 kg ha^{-1} when *Ipomoea* spp. have climbed the sugarcane stalks (Anonymous 2001). A previous study reported that application of atrazine at 2.23 kg ha^{-1} followed by 2,4-D at 0.53 kg ha^{-1} effectively controlled red morningglory; however, control was more consistent when the herbicides were applied to younger plants compared to tall plants (Siebert et al. 2004). In addition, Jones and Griffin (2009) reported that when red morningglory had climbed the sugarcane stalks, 2,4-D remained the most effective treatment because of the efficacy of this herbicide to control *Ipomoea* spp. and crop safety.

Higher rates of diuron and atrazine are used in the United States for PRE weed control in sugarcane (Griffin and Judice 2009); therefore, more research is required to evaluate higher rates of PRE-applied herbicides, which may prolong the period of *Ipomoea* spp. control in sugarcane. Ideally, herbicides selected for control of *Ipomoea* spp. in sugarcane should have both PRE and POST activity and crop safety. Some other PRE and POST herbicides such as oxyfluorfen, flumioxazine, sulfentrazone, terbacil, and azafenidin, and tank mixes of herbicides such as hexazinone plus diuron or 2,4-D plus dicamba need to be investigated for crop safety and control of *Ipomoea* spp. and other weeds in sugarcane in northern India.

Literature Cited

Anonymous. 2001. Louisiana Suggested Chemical Weed Control Guide. Baton Rouge, LA: Louisiana State University AgCenter and Louisiana Co-operative Extension Service Pub. 1565. 195 p.

Anonymous. 2005. Louisiana Agricultural Summary. Baton Rouge, LA: Louisiana State University AgCenter and Louisiana Cooperative Extension Service Pub SP2005-02. Pp. 19–21.

Anonymous. 2011a. Area, Production and Yield of Sugarcane along with Percentage of Coverage under Irrigation in India. New Delhi, India: Ministry of Agriculture, Government of India. 48 p.

Anonymous. 2011b. Modern Irrigation and Fertigation Methodologies for Higher Yields in Sugarcane. Bambhori, Jalgaon, India: Jain Irrigation Systems Ltd., Jain Plastic Park. 45 p.

Ateh, C. M. and R. G. Harvey. 1999. Annual weed control by glyphosate in glyphosate-resistant soybean (*Glycine max*). Weed Technol. 13:394–398.

Barker, M. A., L. Thompson Jr., and R. P. Patterson. 1984. Effect of 2,4-DB on soybeans (*Glycine max*). Weed Sci. 32:299–303.

Egley, G. H. 1990. High temperature effects on germination and survival of weed seeds in soil. Weed Sci. 38:429–435.

Elmore, C. D., H. R. Hurst, and D. F. Austin. 1990. Biology and control of morningglories (*Ipomoea* spp.). Rev. Weed Sci. 5:83–114.

[FAO] Food and Agriculture Organization of the United Nations. 2008. Food and Agricultural Commodities Production: Sugarcane 2008. Rome, Italy: Food and Agriculture Organization of the United Nations. http://faostat.fao.org/site/339/default.aspx. Assessed: July 8, 2011.

Gomes, L. F., J. M. Chandler, and C. E. Vaughan. 1978. Aspects of germination, emergence and seed production of three *Ipomoea* taxa. Weed Sci. 26:245–248.

Griffin, J. L. and W. A. Judice. 2009. Winter weed control in sugarcane. J. Am. Soc. Sugar Cane Technol. 29:128–136.

Griffin, J. L., B. J. Viator, and J. M. Ellis. 2000. Tie-vine (morningglory) control at layby. Sugar Bull. 78:23–35.

Jeyaraman, S., J. Karamathullah, K. Kannappan, and D. Padmanabhan. 2002. Weed management studies in sugarcane—a review. Co-operative Sugar 34:207–217.

Jones, C. A. and J. L. Griffin. 2009. Red morning-glory (*Ipomoea coccinea*) control and competition in sugarcane. J. Am. Soc. Sugar Cane Technol. 29:25–53.

Jordan, D. L., A. C. York, J. L. Griffin, P. A. Clay, P. R. Vidrine, and D. B. Reynolds. 1997. Influence of application variables on efficacy of glyphosate. Weed Technol. 11:354–362.

Kathiresan, G., S. Avudaithai, and K. Kannappan. 2004. Controlling twining weed (*Ipomoea sepiaria*) in sugarcane. Sugar Tech 6:53–58.

Loos, M. A. 1975. Phenoxyalkanoic acids. Pages 1–101. *in* P. C. Kearney and D. D. Kaufman, eds. Herbicides Chemistry, Degradation and Mode of Action. New York: Marcel Dekker, Inc.

Marimuthu, R., S. N. Ahmed, and S. Grigharan. 2002. Control *of Ipomoea* spp. in sugarcane. Indian Sugar 51:807–809.

Millhollon, R. W. 1988. Control of morningglory (*Ipomoea coccinea*) in sugarcane with layby herbicide treatments. J. Am. Soc. Sugar Cane Technol. 8:62–66.

Odero, D. C. and J. A. Dusky. 2011. Weed Management in Sugarcane. Gainesville, FL: University of Florida, Institute of Food and Agricultural Sciences, Florida Cooperative Extension Service Publication # SS-AGR-09, http://edis.ifas.ufl.edu/wg004. Accessed: July 3, 2011.

Ostrofsky, E. B., B. S. Traina, and O. H. Tuovinen. 1997. Variation in atrazine mineralization rates in relation to agricultural management practices. J. Environ. Qual. 26:647–657.

Rangaiah, P. K., R. Durai, S. N. Ahmed, B. J. Pandian, and S. Rajasekaran. 1988. Weed Management in Sugarcane. Sugarcane Research Station, Cuddalore – 607 001. The 16th Annual Meeting of Sugarcane Research and Development Workers. Pennadam, Tamil Nadu, India: Aruna Sugars Ltd.

Reynolds, D. B., D. L. Jordan, P. R. Vidrine, and J. L. Griffin. 1995. Broadleaf weed control with trifluralin plus flumetsulam in soybean (*Glycine max*). Weed Technol. 9:446–451.

Richard, E. P. and C. D. Dalley. 2006. Sugarcane response to flumioxazin. Weed Technol. 20:695–701.

SAS Institute. 2009. SAS User's Guide: Statistics. Version 9.1. Cary, NC: SAS Institute. 451 p.

Siebert, J. D., J. L. Griffin, and C. A. Jones. 2004. Residual effect of 2,4-D on whole stalk and billet planted sugarcane. Weed Technol. 18:304–309.

Singh, A., A. S. Virk, and J. Singh. 2001. Efficacy of a new herbicide for the control of weeds in sugarcane. Sugar Tech 3:63–64.

Thakar, C. and H. N. Singh. 1954. Nilkalamine (*Ipomoea hederacea*)—a menace to sugarcane. Hortic. Abstr. 24:530.

Vencill, W. K., J. W. Wilcut, and C. D. Monks. 1995. Efficacy and economy of weed management systems for sicklepod (*Senna obtusifolia*) and morningglory (*Ipomoea* spp.) control in soybean (*Glycine max*). Weed Technol. 9:456–461.

Viator, B. J., J. L. Griffin, and J. M. Ellis. 2002. Red morningglory (*Ipomoea coccinea*) control with sulfentrazone and azafeniden applied at layby in sugarcane (*Saccharum* spp.). Weed Technol. 16:142–148.

Webster, T. M. 2000. Weed survey—southern states. Proc. South. Weed Sci. Soc. 53:247–274.

Webster, T. M. 2005. Weed survey—southern states: broadleaf crops subsection. Proc. South. Weed Sci. Soc. 58:291–306.

Willis, J. C. 1966. A Dictionary of Flowering Plants and Ferns. Cambridge, UK: Cambridge University Press. 1294 p.

Yassir, A., B. Lagacherie, S. Houot, and G. Soulas. 1999. Microbial aspects of atrazine bio-degradation in relation to history of soil treatment. Pestic. Sci. 55:799–809.

York, A. C., J. W. Wilcut, M. M. Keene, and F. R. Walls Jr.. 1991. Soybean (*Glycine max*) response to postemergence herbicide mixtures containing 2,4-DB. Weed Technol. 5:43–47.

Received August 10, 2011, and approved October 26, 2011.