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Uptake, translocation, and control of trumpet flower (Tecoma stans) with aminocyclopyrachlor

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To gain a better understanding of the physiology of the herbicide aminocyclopyrachlor in young plants of trumpet flower, the uptake and translocation were evaluated after the application of herbicide. This was determined by treating individual leaves with formulated herbicides plus 14C-aminocyclopyrachlor after the application of the formulated herbicide. This experiment used a randomized experimental design with three replications. In addition, field studies were conducted to assess the effectiveness of foliar applications of aminocyclopyrachlor in association with metsulfuron-methyl. The plant absorbed 20% of the herbicide applied. The translocation percentage did not surpass 5% of the total amount applied. Only 1% of the herbicide applied was translocated to the roots. Rate of 40 + 13 g a.i. 100 L−1 of aminocyclopyrachlor+metsulfuron-methyl was effective to control T. stans.

Keywords: Perennial weed, synthetic auxin herbicide, invasive plant, pesticide, absorption, translocation, trumpet flower, ornamental plant, weed control, physiology herbicide.

Introduction

Tecoma stans (L.) Juss. ex Kunth (Bignoniaceae), also known as trumpet flower, is a woody shrub with a wide natural distribution in Mexico and South Florida, and has spread throughout Central America, South America, and the Caribbean.1 Owing to the beauty of its flowering and foliage, this species is used as an ornamental plant in Brazil and other tropical regions around the world. However, there are areas in which the dispersal and germination of seeds have successfully presented invasive behavior.2

This species is considered to be an invasive plant in many regions of the world, including Argentina, Australia, South Africa, Pacific Islands and Atlantic Islands, and Asia.3 In Australia, T. stans grows in dense stands, inhibiting the regeneration of native species areas.4 In Brazil, it was introduced as an ornamental plant, and became an important weed in pastures and non-crop areas.5 In Parana state of Brazil, it was considered unwelcome and its commercialization and production has been forbidden since 1995.6

This species has spread worldwide, developing into many types of soils, semi-arid regions, and tropical areas with high rainfall.7,8 It produces lots of small seeds with membranous wings for prolonged viability.9,10 These seeds are easily spread by wind, and the plant has vegetative propagation abilities through the stem and the root.11 It shows quick and vigorous re-growth when cut; so mechanical control is not effective. Thus, the study of other control methods is necessary.12 Information about the chemical control of this species is scarce. Passini and Kranz13 succeeded in controlling the plant using tebu-thiuron as an herbicide. Oakes14 described control of this plant after applying an association of herbicides: 2.4-D+2.4.5-T in the stem base. Since the root of the plant is gemmifera,6 effective control of this species is only achieved if the herbicide has translocated to the root.

Aminocyclopyrachlor, previously known as DPX MAT28 240 SL, is in development phase by DuPont S/A, and is being tested in Brazil as a new pyrimidine-based
auxin-type herbicide. Its structure is similar to pyridine carboxylic acid herbicides, such as picloram, clopyralid, and aminopyralid. This herbicide has a broad spectrum in controlling annual and perennial weeds, including shrubs and trees. The application of this herbicide is in post-emergence and has a residual effect on soil.

Aminocyclopyrachlor can be absorbed by leaves and roots, translocated through xylem and phloem, and accumulated in the meristematic regions of plants. It has a constant dissociation of 4.65 pKa and log octanol–water partition coefficient (log Kow) between −1.12 and −2.48 when the pH of the aqueous solution increases from 4 to 7, allowing great mobility by phloem.

Effective control of weed species is influenced by initial absorption and subsequent translocation of sufficient herbicide to the site of action when the herbicide is phytotoxic. Since aminocyclopyrachlor is in the experimental phase in Brazil, there are no studies evaluating the uptake and translocation in target species. T. stans is a very difficult-to-control species. Knowing that the herbicide is absorbed and translocated by the plant is especially important for learning about the potential of this herbicide to control other invasive species in tropical areas. The objective of this study was to evaluate the uptake and translocation of aminocyclopyrachlor in foliar application in young plants, and the association of aminocyclopyrachlor with metsulfuron-methyl in controlling T. stans.

Materials and methods

Laboratory studies

Plants of T. stans were cultivated in a greenhouse at the Department of Plant Production in Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba, São Paulo, Brazil. Laboratory analyses were done at Etoxicology Laboratory, CENA/USP, Piracicaba, São Paulo, Brazil.

Seeds of T. stans were collected from the site situated in Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba, São Paulo. Seeds were sowed in pots (100-mm diameter × 70-mm height) containing sieved soil. Physical and chemical characteristics of the soil are presented in Tables 1 and 2.

Eight-leaf plants were selected for treatment. Initially, the third leaf was covered with aluminum foil to prevent

Table 1. Chemical properties of the soil used in the experiment.

<table>
<thead>
<tr>
<th>Depth collection</th>
<th>pH</th>
<th>OM</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>B.S.</th>
<th>CEC</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10</td>
<td>5.4</td>
<td>27</td>
<td>5</td>
<td>4.2</td>
<td>41</td>
<td>15</td>
<td>60.1</td>
<td>72.5</td>
<td>83</td>
</tr>
<tr>
<td>10–20</td>
<td>5.2</td>
<td>21</td>
<td>2</td>
<td>3.6</td>
<td>29</td>
<td>9</td>
<td>40.9</td>
<td>63.9</td>
<td>64</td>
</tr>
</tbody>
</table>

OM: organic material; B.S.: base saturation; V (%): percentage of base saturation.

The treated leaves were washed with a solution containing 1 mL of methanol, 1 mL of deionized water, and 0.2% (v/v) of non-ionic surfactant (Agral) to wash off non-absorbed radioactive material. Scintillation fluid was added, and the radioactivity recovered in the leaf wash was determined in liquid scintillation spectrometry (Packard 1900 TR). The radioactivity present in the liquid from the washed-off leaves and in plant tissues was determined to verify that the sum was close to the total applied.

Plants were transferred to the greenhouse after the application, and the irrigation was performed directly in the soil, avoiding contact with the leaves. Plants were harvested for 2, 4, 8, 12, 24, 48, and 72 h after treatment (HAT) and divided into the following five parts: treated leaves, leaves above the treated leaves, leaves below the treated leaves, stem, and roots.

The treated leaves were washed with a solution containing 1 mL of methanol, 1 mL of deionized water, and 0.2% (v/v) of non-ionic surfactant (Agral) to wash off non-absorbed radioactive material. Scintillation fluid was added, and the radioactivity recovered in the leaf wash was determined in liquid scintillation spectrometry (Packard 1900 TR). The radioactivity present in the liquid from the washed-off leaves and in plant tissues was determined to verify that the sum was close to the total applied.

Plant parts previously divided were oven-dried at 50°C for 48 h, and combusted in a biological oxidizer (OX 600 Harvey Instruments). Herbicide absorption was determined as the percentage of radioactivity present within the plant and the radioactivity was quantified by liquid scintillation spectrometry.

For better visualization of the final position of the radio-labeled herbicide, treated plants were exposed on X-ray film. The plants were treated as described previously; however, after the treated leaves were washed (1 mL of methanol, 1 mL of deionized water, and 0.2% (v/v) of nonionic surfactant), the plants were dried and pressed, and passed on a radio scanner (Cyclone-Packard).

This was a randomized experimental analysis with three replications. To describe the pattern of absorption and translocation of the herbicide, linear and nonlinear regressions were adjusted or uptaken and translocated to different parts of the plant, following Eqs. (1)–(3):

\[
y = a + bx, \tag{1}
\]

\[
y = a'(1 - e^{-bx}), \tag{2}
\]

\[
y = a'(1 - e^{-(bx)^c}), \tag{3}
\]

where \( y \) is the percentage absorbed or translocated; \( a, b, \) and \( c \) are the adjusted parameters of the equation; and \( x \) corresponds to the collection periods (HAT). Models that
met the assumptions of regression were selected (normality and homoscedasticity). If two or more models have adjusted well to the data, we selected the model with the lowest Akaike Criterion $AIC = -2\log(L) + 2p$. We used the software R.

Field studies

Field studies were conducted in Piracicaba, Brazil (22°42′28″ S, 47°37′00″ O) in grazing areas (*Brachiaria decumbens*) with intense infestation of *T. stans*. The site had eutroferric red nitosol, and at the time of application, the temperature was 23.6°C. Herbicide application occurred on May 13, 2011.

We evaluated the effectiveness of aminocyclopyrachlor (395 g kg$^{-1}$) in a mixture with metsulfuron-methyl (126 g kg$^{-1}$) at rates of 40–13; 59–19; 79–25; 119–38 g a.i. dissolved in 100 L of water to control *T. stans*. Nonionic surfactant was added to each herbicide treatment at 0.5% (v/v). The treated plants were the re-growth plants that had a main stem of 1.5-m height on average and an average diameter of 2–4 cm.

Herbicides were applied using CO$_2$ pressurized backpack sprayer at a constant pressure of 2.0 kgf cm$^{-2}$ and liquids doser Guarany$^\text{®}$. Directed applications of 125 mL of the solution of the herbicides were applied. This was a randomized experimental block analysis with four replications, with two plants per replication, amounting to eight plants per treatment.

Visual estimates of defoliation and weed control were performed at 41, 119, and 216 days after the application (DAA). Defoliation was rated on a 0–100% scale, where 0% equals no defoliation and 100% equals total defoliation of plant, compared with a non-treated control group/plant. The weed control was also rated on a 0–100% scale, where 0% equals no plant response and 100% equals plant death. Defoliation data were tested using ANOVA. The Tukey test, with a 5% probability, was used to analyze significant differences among treatments.

Results and discussion

**Laboratory studies**

The values of percentage absorption, total translocation, and translocation to the roots were best described in a non-linear equation (Fig. 1). On the other hand, the translocation to stems, leaves above the treated leaves, and to all the above-ground parts (aerial parts) (stem, leaves above and below the treated leaf) were best described with a linear equation, with adjusted coefficient of determination

<table>
<thead>
<tr>
<th>Depth collection</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Textural class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10</td>
<td>63.8</td>
<td>8.6</td>
<td>2.6</td>
<td>Medium loamy</td>
</tr>
<tr>
<td>10–20</td>
<td>55.1</td>
<td>9.7</td>
<td>35.2</td>
<td>Loamy</td>
</tr>
</tbody>
</table>

Table 2. Physical properties of the soil used in the experiment (%).

Fig. 1. Absorption and translocation of foliar-applied $^{14}$C-aminocyclopyrachlor to *Tecoma stans* at 2, 4, 8, 12, 24, and 72 (HAT), expressed as the percentage of application. Error bars represent the standard error of mean values. Total absorption: $y = 24.15^* (1 - e^{-0.02x})$. Total translocation: $y = 6.02^* (1 - e^{-0.02x})$.

Fig. 2. Translocation of foliar-applied $^{14}$C-aminocyclopyrachlor to the stem leaves below and above *Tecoma stans* at 2, 4, 8, 12, 24, and 72 (HAT), expressed as the percentage of application. Error bars represent the standard error of mean values. Stem translocation: $y = -0.08 + 0.04x$. Leaves below translocation: $y = 0.08^* (1 - e^{-0.09x})$. Leaves above translocation: $y = -0.05 + 0.02x$. 

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Fig. 3. Translocation of foliar-applied $^{14}$C-aminocyclopyrachlor to the above-ground (aerial part) and roots of Tecoma stans at 2, 4, 8, 12, 24, and 72 (HAT), expressed as the percentage of application. Error bars represent the standard error of mean values. Above-ground translocation: $y = -0.19 + 0.06x$. Roots translocation: $y = 1.05 + (1 - e^{-0.08x})$.

($R^2$) of 0.99, 0.94, and 0.99 respectively. This trend suggests that the herbicide still translocates for these areas for a longer period.

A maximum of 20% of the applied radioactivity of aminocyclopyrachlor was absorbed at 72 HAT (Fig. 1). In Cirsium arvense, absorption was 57% of the applied aminocyclopyrachlor in the first 24 HAT. Burke et al. observed a maximum absorption (9.9%) at 72 HAT in plants of Populus tremuloides.

Translocation from the treated leaves to the rest of the plant never exceeded 5% of the applied radioactivity, and the maximum translocation was obtained at 72 HAT (Fig. 1). A similar result was obtained by Bell et al., and it was observed that 3.6% aminocyclopyrachlor translocated in Chondrilla juncea in 72 HAT.

Translocation of a specific herbicide can vary among species. This can occur due to metabolism differences in both the herbicide and the plant. Differences in metabolism can be caused by anatomic or physiological differences among species.

Burke et al. noted that 2% of the aminocyclopyrachlor applied was translocated in P. tremuloides plants in 72 HAT. Mendonça et al. in Memora peregrina plants, another type of Bignoniaceae, registered translocation of only 1.56% of 2,4-D.

Previous researches conducted under field conditions showed that aminocyclopyrachlor controls T. stans effectively, so the amount absorbed and translocated was sufficient to achieve the target site. Bell et al. observed that species sensitive to aminocyclopyrachlor, such as Lactuca serriola, absorbed and translocated less material compared with relatively less sensitive species such as C. juncea. It showed 64.1% of absorption, and the maximum translocation was 8.6% at 24 HAT, while L. serriola showed 5% of absorption and 1% of translocation at 72 HAT.

We realized that greater effectiveness of the herbicide is not associated with higher percentage of absorption and translocation. Bukun et al. observed that auxin herbicide aminopyralid, although more efficient at low doses, was less absorbed and translocated than clopyralid in plants of C. arvense.

Translocation to the leaves above the treated leaves was observed due to herbicide mobility in the phloem and the development stage of the plants used in the studies. Nevertheless, the herbicide can also move through the xylem. We observed that translocation stabilized to the leaves below the treated leaves and roots, whereas this behavior was not observed for the stem and leaves above the treated leaves at 72 HAT (Figs. 2 and 3).

The percentage of aminocyclopyrachlor translocated to roots was approximately 1% at 72 HAT (Fig. 3). Almost the same proportion (1.3%) was translocated to the roots of C. juncea at 72 HAT. Lym observed translocation of 2% of fluoroxypr to the roots of Euphorbia esula.

The sum of the percentages of translocation throughout the above-ground parts of T. stans (all plants excluding roots) was greater (4.23%) than the percentage translocated to the roots (1%) at 72 HAT. Similarly, Bell et al. observed greater translocation of herbicide to the above-ground portions of Centaurea solstitialis, L. serriola, and C. juncea.

Aminocyclopyrachlor was less translocated to the above-ground portion of C. arvense. The authors attributed this behavior to low mobility in phloem, or the growth stage of the plants used in the study.

Lindentmayer et al. observed an almost equal distribution of aminocyclopyrachlor among treated leaves, above-ground tissues, and below-ground tissues with 13, 14, and 14% respectively at 192 HAT in plants of Convolulus arvensis.

Autograph studies of translocation of aminocyclopyrachlor in T. stans confirm the results obtained in this research (Fig. 4). At 2 and 4 HAT, the herbicide was translocated just to the petiole of the treated leaves and had not yet spread to the whole leaf. At 8 HAT, the herbicide was translocated to the stem in the area below the treated leaf, which indicated that the movement of the herbicide is through the xylem and the phloem. At 24 HAT, translocation was observed to the leaves above the treated leaves, and at this period the herbicide had completely spread to treated leaves (the darker regions represent areas of higher radioactivity).

Field studies

No difference in T. stans flower defoliation was detected among treatments. Aminocyclopyrachlor at 40 + 13 g a.i. 100 L$^{-1}$ defoliated 79% of the plants by 41 DAA. The
defoliation rate was 98% by 216 DAA. When evaluating weed control (no sprouting), 59+19 g a.i. 100 L⁻¹ of aminocyclopyrachlor+metsulfuron-methyl provided 100% control, while the rate of 40+13 g a.i. 100 L⁻¹ controlled 88% of T. stans (Table 3). According to Asociación Latinoamericana de Malezas (ALAM), control ranging from 81 to 90% is considered good.

There is limited information about the efficiency of aminocyclopyrachlor on weed control. However, foliar applications of aminocyclopyrachlor only were effective in controlling Diodia virginiana (85%) after the application of 0.11 kg ha⁻¹. This control was comparable with those achieved after the application of herbicides 2,4-D+dicamba+MCPP, commonly used in controlling this plant.[31] When applied to the leaves of Lantana camara, at 0.21 kg ha⁻¹, the control level reached 96%.[32] West et al.[33] achieved 99% of control level in Cayratia japonica after foliar application of 0.35 kg ha⁻¹ of this herbicide.

Isolated application of 2,4-D and clopyralid at 266 and 112 g a.i. ha⁻¹ controlled 74% and 10% of Abutilon theophrasti plants respectively. When the same concentrations...
were applied in combination with metsulfuron-methyl (2.1 g a.i. ha\(^{-1}\)), the control increased to 98% when applied with 2,4-D, and 74% when applied in combination with clopyralid.\[^{[34]}\] These results show that there is a possible synergistic effect of the association of metsulfuron-methyl with other herbicides used to control weeds in pastures.

## Conclusions

This study showed that foliar application of aminocyclopyrachlor + metsulfuron-methyl at 40 + 13 g a.i. 100 L\(^{-1}\) can control *T. stans*. Nearly 20% of the herbicide was absorbed by plant leaves. The total percentage of translocation did not exceed 5%, and only 1% of the applied herbicide was translocated to the roots; in spite of this, the amount translocated was enough to achieve the target site and control the plant. The sum of the percentages of translocation of aminocyclopyrachlor to the above-ground parts of *T. stans* was greater than the percentage translocated to the roots.

## Acknowledgments

The authors are deeply grateful to Dupont Crop Protection for providing herbicides for this study.

## Funding

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### Table 3. Percentage of defoliation and control of *Tecoma stans* after the application of metsulfuron-methyl + aminocyclopyrachlor.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>28</th>
<th>207</th>
<th>378</th>
<th>28</th>
<th>207</th>
<th>378</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMCP + metsulfuron (20 + 6 g a.i. 100 L(^{-1}))</td>
<td>92</td>
<td>99</td>
<td>99</td>
<td>63</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>AMCP + metsulfuron (40 + 13 g a.i. 100 L(^{-1}))</td>
<td>97</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>AMCP + metsulfuron (59 + 19 g a.i. 100 L(^{-1}))</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>AMCP + metsulfuron (79 + 25 g a.i. 100 L(^{-1}))</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>AMCP + metsulfuron (119 + 38 g a.i. 100 L(^{-1}))</td>
<td>99</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Glyphosate (1068 g a.e. 100 L(^{-1}))</td>
<td>99</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Glyphosate (1780 g a.e. 100 L(^{-1}))</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Control treatment[^{[1]}]</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mean</td>
<td>98</td>
<td>99</td>
<td>99</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>F</td>
<td>2.31[^{[ns]}]</td>
<td>3.0[^{[ns]}]</td>
<td>3.0[^{[ns]}]</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>CV (%)</td>
<td>0.82</td>
<td>0.54</td>
<td>0.54</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

\[^{[ns]}\]F-value was not significant at 5% probability.

\[^{[1]}\]In all treatments, except in the control, where Agral 0.5% v/v was added.

\[^{[2]}\]Data are not included in the statistical analysis.

AMCP: aminocyclopyrachlor.

DAA: days after application.

## References

6. Renô, L.R. *Anatomia da raiz e Fenologia de Tecoma Stans (L.) Kunth (Bignoniaceae)*; Maringá State University: Maringá, Brazil, 2002; 36 pp.