Dose and Concentration Responses of Common Nursery Weeds to Gallery, Surflan and Treflan¹

Caren A. Judge², Joseph C. Neal³ and Jerome B. Weber⁴
Department of Horticultural Science, Department of Crop Science
North Carolina State University, Raleigh, NC 27695-7609

Abstract

Preemergence herbicides are applied as often as every eight to ten weeks in container nursery crop production in the southeastern United States. However, weeds often emerge before reaplication. Experiments were conducted to assess the minimum surface-applied doses and the in vitro concentrations of preemergence herbicides required to control susceptible weed species. Greenhouse and outdoor container experiments were conducted to determine surface-applied Treflan (trifluralin) doses required to control large crabgrass and perennial ryegrass. In the greenhouse, 0.8 to 1.1 kg ai/ha (0.7 to 1.0 lb ai/A) was necessary for 6 weeks control. Outdoors, 1.5 to 1.9 kg ai/ha (1.3 to 1.7 lb ai/A) was needed for control 3 weeks after treatment (WAT). However, 6 WAT, 2.6 to 3.4 kg ai/ha (2.3 to 3.0 lb ai/A) was required. Petri dish experiments were conducted to determine the aqueous concentrations of Gallery (isoxaben), Surflan (oryzalin), and Treflan required to control common nursery weeds including eclipta, hairy bittercress, large crabgrass and spotted spurge. The concentration required for 80% shoot inhibition ($I_{80}$) ranged from 0.4 to 1.5 µg ai/mL for Gallery, 1.2 to 9.8 µg ai/mL for Surflan and 1.1 to 73.8 µg ai/mL for Treflan. The relative response of weeds to aqueous concentrations was consistent with reports from outdoor container efficacy trials.

Index words: dinitroaniline, dose-response, preemergence herbicides, container nursery crops.

Species used in this study: eclipta (Eclipta prostrata L.); hairy bittercress (Cardamine hirsuta L.); large crabgrass [Digitaria sanguinalis (L.) Scop.]; spotted spurge (Euphorbia maculata L.); perennial ryegrass (Lolium perenne L.); lettuce (Lactuca sativa L. ‘Black-seeded Simpson’).

Herbicides used in this study: Gallery (isoxaben), N-[3-(1-ethyl-1-methylpropyl)-5-isoxazolyl]-2,6-dimethoxybenzamide; Surflan (oryzalin), 4-(dipropylylamino)-3,5-dinitrobenzenesulfonamide; Treflan (trifluralin), 2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine.

Significance to the Nursery Industry

Container nursery crop producers rely on preemergence herbicides and hand weeding for weed management. Production could be more profitable if herbicide applications were timed more appropriately to reduce the need for hand weeding. Surface-applied Treflan rates necessary for control of susceptible grass species were 0.8 to 1.1 kg ai/ha (0.7 to 1.0 lb ai/A) in the greenhouse and 2.6 to 3.4 kg ai/ha (2.3 to 3.0 lb ai/A) outdoors 6 weeks after treatment (WAT). However, 3 WAT, 1.5 to 1.9 kg ai/ha (1.3 to 1.7 lb ai/A) was needed for equivalent control outdoors, suggesting rapid herbicide losses during this time. Additionally, the petri dish assays demonstrated that the response of nursery weeds to common nursery herbicides is consistent with relative susceptibility in container nursery production and efficacy trials. Because of this, these concentrations may be reliable predictors of herbicide ineffectiveness. An assay or model to predict when herbicide concentrations have dissipated to ineffective levels could improve the timeliness and performance of herbicides, and ultimately reduce the need for hand weeding. These data provide approximate herbicide residue concentrations that could be used in developing such assays.

Introduction

Weeds can significantly reduce the growth of container nursery crops. Fretz (8) reported that just one redroot pigweed (Amaranthus retroflexus L.) or large crabgrass [Digitaria sanguinalis (L.) Scop.] plant per 2.4-liter container reduced dry weight of Japanese holly (Ilex crenata Thunb. ‘Convexa’) by 47% and 60%, respectively. Berchielli-Robertson et al. (1) reported that one plant each of prostrate spurge (Euphorbia humistrata Engelm. ex Gray) and eclipta (Eclipta prostrata L.) were just as competitive as greater numbers of weeds. Creager (3) also reported that a combination of broadleaf and grass weeds reduced the size of container-grown cotoneaster (Cotoneaster dammeri Schneid. ‘Bearberry’ and ‘Lowfast’), Longwood euonymus [Euonymus fortunei (Turcz.) Hand.-Mazz. ‘Longwood’], Japanese holly, juniper (Juniperus horizontalis Moench. ‘Plumosa’), privet (Ligustrum lucidum Ait. f.), pyracantha (Pyracantha coccinea Roem. ‘Lalander’), and azalea [Rhododendron obtusum (Lindl.) Planch. ‘Hino Crimson’].

Since few selective postemergence herbicides are available for use in nursery crops, growers rely heavily upon preemergence herbicides supplemented by hand weeding. It is common in the southeastern United States for preemergence herbicides to be applied every eight to ten weeks during the growing season (19). By this time herbicide concentrations have often dissipated to ineffective levels and emerged weeds must be hand removed between herbicide applications, an expensive and laborious task. Gilliam et al. (11) reported that depending on nursery size, annual hand weeding costs range from $608 to $1401 per hectare ($246 to $567 per acre) based on hourly wages from $3.53 to $3.97, this in addition to 3 herbicide applications per year. More recently, it was reported that in North Carolina it costs up to

¹Received for publication August 6, 2003; in revised form March 30, 2004. This research was partially funded by a grant from The Horticultural Research Institute, 1000 Vermont Avenue, NW, Suite 300, Washington, DC 20005 and research project #NC06169. The authors would like to thank Dr. Ross Leidy for research suggestions and guidance and Dr. Cavell Brownie for statistical guidance and advice on regression analysis. The authors also thank Dow AgroSciences (9330 Zionsville Rd., Indianapolis, IN 46268) and Harrells, Inc. (720 Kraft Rd., Lakeland, FL 33815) for donating chemicals used in this research.

²Graduate Research Assistant.

³Professor of Horticultural Science and Professor of Crop Science, resp.
$1,367 to hand weed 1000 3-liter (0.8 gal) containers over a 4-month period with no herbicide applications, based on average labor costs of $14.75 per hour, as provided by several nurseries (5). If one applies these more current labor costs to the figures provided by Gilliam et al. (11), annual costs for supplemental hand weeding range from $2,389 to $5,506 per hectare ($967 to $2,228 per acre).

The dominant weed species in container-grown crops in the southeastern United States are primarily broadleaf weeds including hairy bittercress (Cardamine hirsuta L.), spotted spurge (Euphorbia maculata L.), and eclipia (4, 6). Annual grasses such as large crabgrass are also common (24, 30). Research has shown that preemergence herbicides currently labeled in container nurseries are effective on these common weeds (3, 10, 17, 22, 27). However, weeds continue to challenge nursery production efficiency.

Most herbicides used in container nurseries contain a dinitroaniline herbicide such as trifluralin, oryzalin, pendimethalin or prodiamine. This family of herbicides provides a wide spectrum of annual grass and small-seeded broadleaf control (25, 28) and offers a broad range of crop tolerance (19). Usually they are prepackaged or tank-mixed with another broadleaf herbicide, such as isoxaben or oxyfluorfen, to provide a broader spectrum of annual grass and broadleaf control (7, 18, 25, 29).

Currently, germinating weed seedlings is the first indication that herbicides have dissipated to ineffective levels. If residual doses of preemergence herbicides in containers could be predicted or estimated by a simple assay, growers could make more timely herbicide applications; thereby, reducing the need for hand weeding. It is first necessary to determine effective surface-applied preemergence application rates necessary for weed control. Additionally, effective herbicide concentrations for preemergence control of common nursery weeds have not been reported. Isoxaben effectively reduced radical growth of common cereal grain weeds [scentless chamomile (Matricaria perforata Merat.), ladysthumb (Polygonum persicaria L.), common chickweed (Stellaria media (L.) Vill.), Persian speedwell (Veronica persica Poir.), and field violet (Viola arvensis Murr.)], by 50% at solution concentrations between 0.01 and 0.08 mg ai/liter (12). We employed similar methods to determine inhibitory concentrations of isoxaben and other nursery herbicides on important nursery weeds. Therefore, the objectives of this research were to determine the surface-applied Treflan (trifluralin) rates necessary for effective residual control of two sensitive grass species, large crabgrass and perennial ryegrass (Lolium perenne L.), and to determine the critical aqueous concentrations of commonly used preemergence herbicides necessary for control of problem weeds in container nursery crop production.

Materials and Methods

Surface-applied Treflan (trifluralin) dose-response. A preliminary Treflan dose-response test was conducted in the greenhouse to determine which of several common nursery weeds, including eclipia, hairy bittercress, large crabgrass, and spotted spurge, would be appropriate bioassay species. Lettuce was also included. Shoot fresh weight and visual estimates of percent inhibition, compared to nontreated plants based on a 0 to 100% scale, with 0 equal to no plant response and 100% equal to complete weed control, were determined 6 weeks after treatment (WAT). Across these two parameters, no consistent Treflan control was observed on eclipia, hairy bittercress, spotted spurge, or lettuce (data not shown); thus, a dose-response did not occur with these broadleaf species. However, a dose-response was observed with large crabgrass. Consequently, subsequent dose-response experiments were conducted using large crabgrass and also including perennial ryegrass as bioassay species. Perennial ryegrass was added because it is another grass species with sensitivity to Treflan that germinates quickly and uniformly, and is readily available.

Based on the results of the preliminary greenhouse experiment, a dose-response experiment was conducted in the greenhouse and repeated outdoors. The first experimental repetition in the greenhouse utilized 1.25 liter (0.3 gal), 15 cm (5.9 in) diameter plastic containers. The potting substrate was a pine bark:sand mix (7:1 v/v) amended with 3.6 kg per m$^3$ (6 lbs per yd$^3$) pulverized dolomitic limestone and 5.9 kg per m$^3$ (10 lbs per yd$^3$) Wilbro 15N–1.8P–7.5K with micros controlled release fertilizer (Harrells, Inc., 720 Kraft Rd., Lakeland, FL). Approximately 1 teaspoon each of large crabgrass and perennial ryegrass seeds were surface-sown to potting substrate. Treflan 4EC, trifluralin (Dow AgroSciences, 9330 Zionsville Rd., Indianapolis, IN), application rates were 0 (nontreated), 0.07, 0.14, 0.28, 0.56, 1.12 and 2.24 kg ai/ha [0, 0.06, 0.13, 0.25, 0.50, 1.00 and 2.00 lb ai/A]. Applications were made to the substrate surface using a belt sprayer with one TeeJet 8001 even flat fan nozzle (Spraying Systems Co., P.O. Box 7900, Wheaton, IL) at a height of 31.8 cm (12.5 in) calibrated to deliver 187 liters/ha (20 gal/A) at 241 kPa (35 PSI). Immediately following herbicide application and daily thereafter, containers were hand-watered overhead to container capacity. The experimental design was a randomized complete block with four single-container replications. Percent inhibition was visually evaluated 6 WAT compared to nontreated plants on a 0 to 100% scale, with 0 equal to no plant response and 100% equal to complete weed control. Shoot fresh weight was also determined 6 WAT. Visual evaluations were highly correlated with shoot fresh weights (correlation coefficients 0.84 to 0.95, depending on species and experimental repetition). Therefore, for presentation purposes, only visual evaluations of percent inhibition data are presented herein.

The dose-response experiment was repeated outdoors with the following differences. Container size was 11.4 liters (3 gal) and 25 cm (10 in) diameter. Treflan applications were made using a CO$_2$ pressurized backpack sprayer equipped with two TeeJet 8003 flat fan nozzles calibrated to deliver 280 liters/ha (30 gal/A) at 276 kPa (40 PSI). Because no control was achieved in the greenhouse with 0.07 kg ai/ha (0.063 lbs ai/A), this rate was not included in the outdoor test. Previous research and experience have shown that higher rates are required outdoors for control similar to that observed in greenhouse tests; therefore, the highest labeled rate for Treflan in container nurseries, 4.48 kg ai/ha (4.0 lbs ai/A), was added. Following application, containers were overhead irrigated receiving approximately 8.5 mm (1/3 in). Each day thereafter, containers were overhead irrigated receiving two separate cycles of approximately 8.5 mm (1/3 in) each cycle. Percent inhibition evaluations were the same as in the greenhouse study with the addition of a visual evaluation of percent inhibition 3 WAT.

Data were subjected to analysis of variance and non-linear regression (SAS Proc NLIN) (23). Since data were rela-
tive to the nontreated, the zero rate was not included in the analyses. Rate responses were fitted using non-linear least squares to a logistic model described by Rawlings et al. (21) shown in Equation 1. The upper asymptote was set at 100, assuming that with high enough rates; inhibition will reach 100%. Additionally, rates required to obtain 80% control ($I_{80}$) were estimated by solving Equation 1.

Equation 1: $Y = \frac{100}{(1 + Be^{-KX})}$

Where:
- $Y =$ Percent large crabgrass or perennial ryegrass inhibition
- $X =$ Log$_{10}$ of the herbicide application rate in kg ai/ha
- $B$ and $K =$ Estimated parameters
- $e =$ 2.718 (Napier's constant)

**Aqueous concentration responses.** Petri dish experiments were conducted to determine aqueous herbicide concentrations required to control eclipta, hairy bittercress, large crabgrass, and spotted spurge. In addition, lettuce (*Lactuca sativa* L. ‘Black-seeded Simpson’) and perennial ryegrass were used as potential bioassay species, the latter only in the Treflan experiment. Each experimental repetition was conducted in a randomized complete block design with four replications, and was repeated. Herbicides investigated included two dinitroanilines, Surflan 4 AS, oryzalin (Dow AgroSciences), and Treflan 4 EC. Gallery 75 DF, isoxaben (Dow AgroSciences), principally used for broadleaf control, was also included. The water solubility of Gallery, Surflan and Treflan are low, 1.0 mg/liter, 2.6 mg/liter, and 0.3 mg/liter, respectively (26). Therefore, commercial formulations were used to facilitate suspension in water. Treatment solution concentrations for each herbicide were 0 (nontreated), 0.01, 0.05, 0.10, 0.50, 1.00 and 5.00 µg ai/mL. An experimental repetition consisted of each of the six weed or bioassay species and the seven concentrations of each herbicide (including the zero concentration).

Three Whatman #1 filter papers (Whatman Inc., 9 Bridgewell Place, Clifton, NJ) were placed in 9 cm (3.5 in) diameter glass petri dishes and 5 mL of the appropriate herbicide solution was added to each petri dish. Twenty-five seeds of each weed or bioassay species were placed in petri dishes, each species in a separate dish. Petri dishes were wrapped with plastic film and incubated in a growth chamber automated to receive a 14 h photoperiod at 24C (75F) and 10 h dark at 18C (64F). Plant shoot and root length were measured 7 to 9 days after initiation, depending upon the growth rate of each species. Data were expressed as percent inhibition, compared to the nontreated. Herbicide treatments did not affect percent seed germination; therefore, non-germinated seeds were not included in the average.

Data from both experimental repetitions were pooled for analysis. Percent inhibition data were subjected to analysis.
of variance and non-linear regression (SAS Proc NLIN) (23). Since data were relative to the nontreated, the zero rate was not included in the analyses. Concentration responses were fitted using non-linear least squares to a Gompertz model described by Johnson and Kotz (13) shown in Equation 2. The upper asymptote was set at 100, assuming that with high enough rates inhibition will reach 100%. Additionally, concentrations required to obtain 80% control ($I_{80}$) were estimated by solving Equation 2.

Equation 2: $Y = 100e^{-e^{-B*_{e^{-K*(X+3)}}}}$
Where:
$Y$ = Percent root or shoot inhibition
$X$ = Log$_{10}$ of the herbicide concentration in µg ai/mL
$B$ and $K$ = Estimated parameters
e = 2.718 (Napier's constant)

Results and Discussion

Surface-applied Treflan (trifluralin) dose-response. Treflan dose-response data were fitted to logistic models (Fig. 1). From these regression models, the concentration required to achieve 80% inhibition ($I_{80}$) of large crabgrass and perennial ryegrass were determined for each experimental repetition (Table 1). In the greenhouse, 0.8 to 1.1 kg ai/ha (0.7 to 1.0 lb ai/A) was necessary for 80% inhibition of both large crabgrass and perennial ryegrass 6 WAT (Table 1). Outdoors, 1.9 to 1.5 kg ai/ha (1.7 to 1.3 lb ai/A) was needed for 80% control of large crabgrass and perennial ryegrass 3 WAT, respectively (Table 1). However, 6 WAT, 3.4 and 2.6 kg ai/ha (3.0 and 2.3 lb ai/A) was required for large crabgrass and perennial ryegrass inhibition, respectively (Table 1). Based on these data, preemergence control of sensitive grass species can be obtained for at least six weeks with labeled rates [up to 4.4 kg ai/ha (4.0 lb ai/A)] of Treflan in container production. Additionally, since lower rates were required 3 WAT than 6 WAT, it is likely that rapid trifluralin losses are occurring during this time period. Our previous research has demonstrated the half-life of trifluralin is less than 7 days in soilless substrates, much lower than in soils (16).

Aqueous concentration responses. Concentration responses were fitted to Gompertz models. Based on the regression equations for Gallery (Fig. 2), Surflan (Fig. 3), and Treflan (Fig. 4), $I_{80}$ values were determined for each species and herbicide combination (Table 2). The lower the $I_{80}$ value, the more sensitive the species is to the herbicide indicating it requires a lower concentration to effectively inhibit the root or shoot growth by 80%. Root responses in the petri dish cultures were similar, but not as consistent as shoot responses.

Table 1. Treflan (trifluralin) rate (kg ai/ha) required for 80% inhibition ($I_{80}$) of large crabgrass (Digitaria sanguinalis) and perennial ryegrass (Lolium perenne), as determined by dose-response experiments conducted in the greenhouse and outdoors.

<table>
<thead>
<tr>
<th>Evaluation date</th>
<th>Large crabgrass</th>
<th>Perennial ryegrass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preliminary</td>
<td>Greenhouse</td>
</tr>
<tr>
<td></td>
<td>Greenhouse</td>
<td>Outdoors</td>
</tr>
<tr>
<td>3 WAT$^a$</td>
<td>n/a$^a$</td>
<td>n/a</td>
</tr>
<tr>
<td>6 WAT</td>
<td>0.84</td>
<td>1.08</td>
</tr>
</tbody>
</table>

$I_{80}$ values (n = 4) determined from regression equations (Fig. 1).
$^a$Weeks after treatment.
$^b$Not available.

![Fig. 2. Shoot inhibition 7 to 9 days after treatment (expressed as a percent of the nontreated) of (A) eclipta, ecl, (Eclipta prostrata) and hairy bittercress, hh, (Cardamine hirsuta); (B) spotted spurge, ss, (Euphorbia maculata) and lettuce, let, (Lactuca sativa 'Black-seeded Simpson'); and (C) large crabgrass, lc, (Digitaria sanguinalis) by aqueous concentrations of Gallery (isoxaben). Data were fitted to a Gompertz model: $Y = 100e^{-a_{e^{-b_{e^{-K*(X+3)}}}}}$, where $X = Log_{10}$ Gallery concentration (µg ai/mL).](image)
Therefore, shoot responses were deemed the best parameter to estimate effective herbicide concentrations. Based on shoot response $I_{90}$ values, the three broadleaf weeds, eclipta, hairy bittercress, and spotted spurge, had similar relative responses to the herbicides, with Gallery being the most effective, followed by Surflan and Treflan (Table 2). Eclipta and hairy bittercress $I_{90}$ values for Surflan and Treflan were beyond the range of concentrations tested, as well as for the spotted spurge and Treflan combination. Thus, $I_{90}$ values were extrapolated using the regression equation. Since Gallery is primarily a broadleaf herbicide (20) and is labeled for control of hairy bittercress, eclipta and spotted spurge at 1.12 kg ai/ha (1.0 lb ai/A), it is not surprising the broadleaf weeds were more sensitive to Gallery than to Treflan or Surflan, which are mainly grass herbicides.

When examining each herbicide separately across weed species, Gallery was most effective on hairy bittercress ($I_{90} = 0.4 \mu g \text{ ai/mL}$), followed by spotted spurge ($I_{90} = 0.5 \mu g \text{ ai/mL}$) and eclipta ($I_{90} = 1.3 \mu g \text{ ai/mL}$) (Table 2). The concentration of Gallery required to control susceptible broadleaf weeds reported herein are similar to those previously reported to control common broadleaf weeds of cereal crops (12). Gallery also provided substantial shoot reduction of lettuce, the broadleaf bioassay species ($I_{90} = 1.6 \mu g \text{ ai/mL}$) (Table 2). The ranking of weed responses is similar to that reported in traditional herbicide efficacy trials. In outdoor container ex-
Table 2. Aqueous concentrations of Gallery (isoxaben), Surflan (oryzalin) and Treflan (trifluralin) required for 80% inhibition (I₈₀) of shoot growth of eclipia (Eclipta prostrata), hairy bittercress (Cardamine hirsuta), spotted spurge (Euphorbia maculata), lettuce (Lactuca sativa, ‘Black-seeded Simpson’), large crabgrass (Digitaria sanguinalis), and perennial ryegrass (Lolium perenne), as determined by petri dish assays.

<table>
<thead>
<tr>
<th>Species</th>
<th>Gallery</th>
<th>Surflan</th>
<th>Treflan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eclipta</td>
<td>1.3</td>
<td>9.8⁺</td>
<td>73.8⁺</td>
</tr>
<tr>
<td>Hairy bittercress</td>
<td>0.4</td>
<td>5.9⁺</td>
<td>17.3⁺</td>
</tr>
<tr>
<td>Spotted spurge</td>
<td>0.5</td>
<td>1.2</td>
<td>6.2⁺</td>
</tr>
<tr>
<td>Lettuce</td>
<td>1.6</td>
<td>17.4⁺</td>
<td>7.2⁺</td>
</tr>
<tr>
<td>Large crabgrass</td>
<td>1.5</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Perennial ryegrass</td>
<td>n/a</td>
<td>n/a</td>
<td>0.9</td>
</tr>
</tbody>
</table>

I₈₀ values (n = 8) determined from regression equations (Figs. 2 to 4).  
⁺Extrapolated values.  
⁻Not available.

experiments, Gallery has been shown to provide good control of hairy bittercress but is less effective on eclipia and spotted spurge (14). Eclipia, hairy bittercress and lettuce did not respond to Surflan within the range of concentrations tested, but spotted spurge did show a response (I₈₀ = 1.2 µg ai/mL) (Table 2). Surflan has been shown to control spotted spurge (7, 14, 27), and has also been shown to provide moderate to good control of hairy bittercress, but poor control of eclipia (14, 27).  

Eclipia, hairy bittercress, spotted spurge and lettuce did not respond to Treflan within the range of concentrations tested (Table 2). Poor control of these and other broadleaf weeds with trifluralin is common in container experiments (9, 14). Weatherspoon and Currey (27) did report control of hairy bittercress and spotted spurge with Treflan. However, this was at a rate of 5.6 kg ai/ha (5.0 lb ai/A), higher than the currently labeled rate of 4.48 kg ai/ha (4.0 lb ai/A).  

The response of the grass species to the herbicides was unexpectedly different compared to the broadleaf species. For large crabgrass, Treflan was the most effective (I₈₀ = 1.1 µg ai/mL) followed by Surflan (I₈₀ = 1.2 µg ai/mL) and Gallery (I₈₀ = 1.5 µg ai/mL) (Table 2). The Treflan I₈₀ value (0.9 µg ai/mL) for perennial ryegrass was similar to that for large crabgrass (Table 2). Similarly, Fretz (10) reported excellent control of large crabgrass with 4.48 kg ai/ha (4 lb ai/A) Treflan in container experiments. Surflan controlled large crabgrass in container experiments (2, 14, 30), Additionally, Gallery can have marginal activity on large crabgrass (18). However, labeled rates of Gallery [1.12 kg ai/ha (1.0 lb ai/A)] are much lower than those of Surflan and Treflan [4.48 kg ai/ha (4.0 lb ai/A)]. Thus, large crabgrass control in containers with Gallery is usually poorer than with Surflan or Treflan (14).  

The relative response of problem weeds to common nursery herbicides documented in this research is consistent with previously reported herbicide susceptibilities. Because of this, the minimum effective concentrations reported herein may be reliable predictors of herbicide effectiveness. The overall goal is that during periods of rapid herbicide loss, these data can be used as a baseline for the development of an assay or model to predict exactly when herbicide concentrations are lower than effective levels. This could improve the timeliness and performance of herbicides and ultimately reduce the need for hand weeding.

Literature Cited


