ABSTRACT

JUDGE, CAREN ANN. Predicting Herbicide Dissipation in Container Nursery Crop Production – A Method for Improving Herbicide Performance and Reducing Hand Weeding. (Under the direction of Joseph C. Neal.)

In southeastern U.S. container nursery crop production, frequent applications of preemergence herbicides supplemented by hand weeding are relied upon for broad-spectrum weed control during the growing season. Experiments were conducted to determine the aqueous concentrations required for weed control, to relate this to surface-applied rates, and to determine trifluralin dissipation in container substrates. Petri dish experiments were conducted to determine the aqueous concentration required for control of common nursery weeds including *Eclipta prostrata*, *Cardamine hirsuta*, *Digitaria sanguinalis* and *Euphorbia maculata*. Lettuce (*Lactuca sativa* 'Black-seeded Simpson'), oats (*Avena sativa* 'Rodgers') and perennial ryegrass (*Lolium perenne*) were also included as potential bioassay species. Herbicides evaluated were isoxaben, oryzalin, and trifluralin. The relative response of weeds to aqueous concentrations was similar to that observed in efficacy trials. Concentrations of Gallery required for 80% inhibition (I_{80}) were 1.3 and 0.4 for eclipta, 0.4 and 3.9 for hairy bittercress, 0.5 and 0.3 for spotted spurge, 1.5 and 0.3 for large crabgrass, and 1.6 and 0.1 μg ai/mL for lettuce shoot and root, respectively. I_{80} values for Surflan were 9.8 and 0.4 for eclipta, 5.9 and 1.6 for hairy bittercress, 1.2 and 1.4 for spotted spurge, 1.2 and 0.1 for large crabgrass, and 17.4 and 0.6 μg ai/mL for lettuce shoot and root, respectively. I_{80} values for Treflan were 73.8 and 3.4 for eclipta, 17.3 and 7.4 for hairy bittercress, 6.2 and 9.2 for spotted spurge, 1.1 and 0.5 for large crabgrass, 7.2 and 8.4 for lettuce, and 0.9 and 1.2 μg ai/mL for perennial ryegrass shoot and root, respectively. Oat I_{80} values were well beyond the concentration range tested and extrapolated values were not realistic for Gallery and

Surflan. However, Treflan I_{80} values were 0.5 and 2.1 μg ai/mL for shoot and root inhibition, respectively. Treflan dose-response experiments were conducted in the greenhouse and outdoors to determine the surface-applied rates necessary for preemergence control of large crabgrass and perennial ryegrass. The rates of Treflan in the greenhouse were 0.07 to 2.24 kg ai/ha and outdoors were 0.14 to 4.48 kg ai/ha. Percent control was estimated 3 and 6 weeks after treatment (WAT); shoot fresh weights were measured 6 WAT. In the greenhouse, approximately 1.0 kg ai/ha was necessary to control both species. Outdoors, less than 2.0 kg ai/ha was needed for control of both species 3 WAT. By 6 WAT, 2.6 and 3.4 kg ai/ha were required to control perennial ryegrass and large crabgrass, respectively. Additionally, an experiment was conducted at two locations to determine the dissipation of Preen (trifluralin) in a pine bark plus sand potting substrate and to compare grass inhibition over time. Preen was surface applied at 4.5 kg ai/ha, then large crabgrass and perennial ryegrass were seeded 0, 1, 2, 4, 6 and 8 WAT. Shoot and root growth were measured two weeks after seeding. Substrate samples taken 0, 1 and 3 days after treatment and 1, 2, 4, 6 and 8 WAT from the top 2 cm of the potting substrate were extracted and trifluralin content quantified by gas chromatographic techniques. In the March to May test, 50% weed growth occurred approximately 7 WAT, at which time weeds emerged and flourished. However, in the May to July test, trifluralin dissipated more rapidly. Growth (50%) occurred within 2 to 7 weeks after application, depending on species. These data suggest that trifluralin residues in the surface of the potting substrate decrease rapidly after application and slowly thereafter reaching what may be considered critically low levels approximately 4 to 6 weeks after application. These results suggest that for trifluralin, the common reapplication interval of 8 to 10 weeks in the southeastern U.S. may need to be shortened to 4 to 6 weeks.

Predicting Herbicide Dissipation in Container Nursery Crop Production – A Method for Improving Herbicide Performance and Reducing Hand Weeding

by

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Dedication

to

Terry R. Wright, Ph.D.

For introducing me to weed science and helping me get my foot in the door. Most importantly, however, for believing in me long before I or anyone else did. You have been a terrific mentor, friend and inspiration. I owe my entire weed science career to you and I have tried to build on the foundation that you have laid by your guidance. You have shown me the meaning of integrity, hard work, and sound science. I can only aspire to be as prosperous, in all facets of life, as you have been and continue to be in yours. Thanks always. I hope I can make you proud.

Biography

Caren Judge was born Caren Ann Schmidt (Carrie) in Lansing, Michigan and grew up nearby in rural St. Johns enjoying the outdoors, sports, theatre, family and friends. After high school, she started freshman year as an accounting major. Carrie realized she enjoyed the outdoors and getting her hands dirty far too much to be permanently stuck in an office. Carrie eventually ended up at Michigan State University where during her senior year, she began working part-time in the laboratory of the esteemed weed sceintist, Dr. Donald Penner. This is where her weed science career officially began. During her last semester, Carrie traveled abroad to Nepal for an overseas study program in agriculture and returned to graduate with honors in 1997 with a Bachelors of Science in Agriscience, with an emphasis in agronomy. Shortly thereafter Carrie found work at BASF as a research assistant in the weed science group, thanks to the help of a former graduate student in Dr. Penner's lab. Finally, she decided she could not fight it anymore…weed science is where she would stay. After two years of work, she began her graduate career under the direction of Dr. Joe Neal in the department of Horticultural Science researching herbicide dissipation in container substrates. During her program, she married Stephen Judge of Rocky Mount, North Carolina. Upon completion, Carrie will continue her Ph.D. graduate work at North Carolina State University switching gears to the biology and ecology of invasive plants. She hopes to find a career in invasive plant ecology.

Acknowledgement

The author would like to expressly thank Dr. Joseph C. Neal for his guidance and direction during the last two years. Thanks go to Dr. Ross B. Leidy for serving on the advisory committee and for working through all the trials and tribulations of the residue analysis portion of the research. Thanks to Dr. Jerome B. Weber for serving on the advisory committee, offering suggestions and making committee meetings very thought-provoking. The statistical expertise of Dr. Cavell Brownie was also greatly appreciated. A special thanks goes to all who offered technical support, including, but not limited to, Robbie Wooten, Len Swain, Tina Fernandez, Dr. Gail Mahnken, Gina Penny, Jennifer Cook, Sandy Cook, and Scott Newkirk. Additional thanks go to the graduate students in the departments of Horticultural Science, Toxicology and Crop Science for the good times and support. A very special thanks to my family for their encouragement, support and shoulders to lean on. Finally, thanks to my husband, Stephen, for his unending support, encouragement and small sacrifices for the big rewards to come someday. I love you.

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Scope and Justification

Weeds compete for water, light, nutrients and space in container nursery crop production. Fretz (1972) reported that in 2.4-liter nursery containers, just one plant each of redroot pigweed and large crabgrass reduced the dry weight of Japanese holly by 47% and 60%, respectively. Similarly, Berchielli-Robertson et al. (1987) reported that one plant each of prostrate spurge and eclipta were just as competitive as greater amounts of weeds. Craeger (1982) reported that a combination of broadleaf and grass weeds reduced the size of several ornamental species including cotoneaster, azalea, euonymus, pyracantha and holly. Unlike agronomic crops where threshold levels determine the amount of weed control necessary, it is generally unacceptable for nursery containers to have any weeds not only because of competition, but also due to aesthetics and marketability.

In the southeastern U.S., frequent preemergence herbicide applications, every 8 to 10 weeks, supplemented with hand weeding are required to adequately control weeds in container nurseries. Few postemergence herbicides are available for selective removal of emerged weeds. Despite the fact that currently labeled preemergence herbicides can dramatically reduce the need for hand weeding (Darden and Neal, 1999), frequent hand weeding is still required for weed emergence that occurs between preemergence herbicide applications. Hand weeding requires a great deal of labor and money in addition to the cost of the herbicides. Gilliam et. al. (1990) reported that the annual cost of hand weeding can range from $608 to $1401 per hectare ($246 to $567 per acre) based on hourly wages of $3.53 to $3.97, this in addition to 2.9 to 3.2 herbicide applications per year. In North Carolina, it was reported that without herbicide applications it may cost as much as $1,367 to hand weed 1000 pots over a 4-month period based on hourly wages of $14.75, an average labor cost provided by local nurseries (Darden and Neal, 1999). If one applies these more current labor costs to the figures provided by Gilliam et al., the cost for supplemental hand weeding could 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 U.S. are mainly broadleaf weeds including hairy bittercress (*Cardamine hirsuta*), spotted spurge (*Euphorbia maculata*) and eclipta (*Eclipta prostrata*) (Cross and Skroch, 1992; Derr, 1989). Annual grasses including large crabgrass (*Digitaria sanguinalis*) are also common (Singh et al., 1980; Wilcut et al., 1989). Standard weed management systems in southeastern U.S. nursery crop production may include up to six preemergence herbicide applications per year. Research has shown that preemergence herbicides currently labeled in container nurseries are effective on these major problem weeds (Creager, 1982; Derr, 1994; Gallitano and Skroch, 1993; Monaco and Hodges, 1974; Ruter and Glaze, 1992; Singh et al., 1980; Stamps and Neal, 1990; Weatherspoon and Currey, 1979; Wilcut et al., 1989;). Despite the effectiveness of many of these herbicides, these dominant weeds continue to challenge growers. Evidence suggests that these herbicides will control target weeds for 7 to 12 weeks depending upon the type of potting substrate, irrigation practices, herbicide rate used, and weather conditions (Judge and Neal, 2000). Since these weeds continue to persist, this implies that the concentration of the herbicide in the substrate surface where weeds are germinating has dissipated to ineffective levels. This could be due to leaching, volatilization or microbial degradation.

Currently, nursery growers have no tools or models, other than weed emergence, to predict when herbicides have dissipated to inadequate concentrations for weed control. In order to develop such an assay system for growers to quickly and reliably predict herbicide dissipation, it is critical to know the herbicide concentrations that are effective on problem weeds. Little research has been done to determine critical (or threshold) concentrations for preemergence herbicides in aqueous extracts of soilless media. In vitro concentrations of isoxaben (Gallery) have been reported for common broadleaf weeds of small grain cropping systems (Huggenberger and Ryan, 1985). However, such work has not been reported on important weeds or for other herbicides of container nurseries. Additionally, no quantitative data have been reported on the dissipation of herbicides in container nursery substrates.

In container nursery crop production, most preemergence herbicide programs include a dinitroaniline (DNA) herbicide (oryzalin, pendimethalin, prodiamine or trifluralin) for their efficacy on annual grass and small seeded broadleaf control (Stamps and Neal, 1990; Weber and Monaco, 1972), and their broad range of crop tolerance (Neal et al., 1999). Often they are prepackaged with a more effective broadleaf component such as oxyfluorfen or isoxaben to achieve broad-spectrum weed control (Derr, 1994; Gallitano and Skroch, 1993; Neal and Senesac, 1991; Ruter and Glaze, 1992; Stamps and Neal, 1990; Whitwell and Kalmowitz, 1989). Preemergence herbicide mixtures commonly used in container nurseries include OH2 (oxyfluorfen + pendimethalin), Rout (oxyfluorfen + oryzalin) and Snapshot TG (isoxaben + trifluralin).

Trifluralin was the first of the DNA herbicides to be registered in 1963 (Weber, 1990) and is the most widely used of the DNA's (Peter and Weber, 1985). Trifluralin has a very low water solubility of 0.3 μg/mL (Ahrens et al., 1994), but is readily soluble in organic solvents (Tepe and Scroggs, 1967). Because of its low water solubility, it is not likely to leach in soils (Laabs et al., 2000) or container substrates (Elmore et al., 1976; Wilson et al., 1996). Additionally, trifluralin is susceptible to decomposition by ultraviolet irradiation

(Tepe and Scroggs, 1967) and has a high vapor pressure that causes it to volatilize (Weber and Monaco, 1972; Weber, 1990). In agronomic crop production, Treflan (trifluralin) is often soil incorporated to reduce volatilization. However, in nursery production, this is not feasible. Therefore, a granule formulation is often used either as Preen, Trifluralin 5G or Snapshot TG. Volatility is reduced if irrigation follows shortly after application especially during high temperature months. Trifluralin is strongly sorbed to soil especially organic, lipophilic, and/or proteinaceous substances (Weber, 1990).

The average half-life of trifluralin in most field soils is 45 days with less than 10% remaining one year after application (Ahrens et al., 1994). The half-life is longer in cool, dry areas (Ahrens et al., 1994). In a review of dinitroanilines, the half-life of trifluralin ranges from 19 to 132 days in various field trials (Weber, 1990). Laabs et al. (2000) reported the half-life of trifluralin to be less than 1 day in a Brazilian tropical region and attributed the fast initial disappearance to chemical and microbial degradation, volatilization and physical losses. While trifluralin persistence has been reported for many field soils, no data is available on trifluralin dissipation in soilless nursery substrates. Most nursery substrates include organic materials such as pine bark, peat moss, rice hulls, wood shavings and sawdust (Wehtje et al., 1993). In the southeastern U.S., pine bark is the predominant component. Based on the need for frequent herbicide re-application to maintain acceptable weed control, it is likely that the half-life in the surface of soilless substrates is less than those observed in field soils.

Prior to use of any model or assay, weed inhibition threshold concentrations for nursery herbicides on common nursery weeds must be established for aqueous extracts of soilless media. Additionally, these concentrations must be correlated with the amount of preemergence herbicide applied to the surface of a potting substrate. Herbicide concentrations need to be monitored over time in a container nursery production situation. Finally, the growth of sensitive species must be monitored over time to determine how these concentrations relate to weed inhibition.

Therefore the objectives of this dissertation research were 1) To determine the critical aqueous concentrations necessary for control of problem weeds with common herbicides of container nursery production, 2) To focus on trifluralin and determine surface-applied rates necessary for effective preemergence control of two sensitive grass species and 3) To quantitatively determine trifluralin dissipation over time in a soilless nursery substrate and relate this to weed growth of sensitive grass species over time.

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Chapter 1

Concentration and Dose-response of Gallery, Surflan and Treflan on Common Nursery Weeds

(In the format appropriate for submission to Journal of Environmental Horticulture)

Concentration and Dose-response of Gallery, Surflan and Treflan on Common Nursery Weeds[1]

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Abstract

During the growing season in the southeastern U.S., preemergence herbicides are applied every 8 to 10 weeks in container nurseries. These applications are supplemented by hand weeding, a laborious and expensive task. To reduce the need for hand weeding, growers might welcome a quick and reliable assay that can determine if herbicide concentrations are adequate for weed control. Based on this premise, experiments were conducted to determine the aqueous concentrations required for weed control and to relate this to surface-applied rates. Petri dish experiments were conducted to determine the aqueous concentrations of Gallery (isoxaben), Surflan (oryzalin), and Treflan (trifluralin) required to control common nursery weeds including elipta, hairy bittercress, large crabgrass and spotted spurge. Two potential bioassay crop species, lettuce and oats, were also included. Additionally, perennial ryegrass was included with the Treflan experiment. The relative response of weeds to aqueous concentrations was similar to that observed in efficacy trials. Concentrations of Gallery required for 80% inhibition (I_{80}) were 1.3 and 0.4 for eclipta, 0.4 and 3.9 for hairy bittercress, 0.5 and 0.3 for spotted spurge, 1.5 and 0.3 for large crabgrass, and 1.6 and 0.1 μg ai/mL for lettuce shoot and root, respectively. Surflan I_{80} values were 9.8 and 0.4 for eclipta, 5.9 and 1.6 for hairy bittercress, 1.2 and 1.4 for spotted spurge, 1.2 and 0.1 for large crabgrass, and 17.4 and 0.6 μg ai/mL for lettuce shoot and root, respectively. Treflan I_{80} values were 73.8 and 3.4 for eclipta, 17.3 and 7.4 for hairy bittercress, 6.5 and 9.2 for spotted spurge, 1.1 and 0.5 on large crabgrass, 7.2 and 8.4 for lettuce, and 0.9 and 1.2 μg ai/mL for perennial ryegrass shoot and root, respectively. I_{80} values for oats were well beyond the concentration range tested and extrapolated values were not realistic for Gallery or Surflan. However, Treflan I_{80} values were 0.5 and 2.1 μg ai/mL for oat shoot and root, respectively.

Treflan dose-response experiments were also conducted in the greenhouse and outdoors to determine the surface-applied rates necessary for preemergence control of large crabgrass and perennial ryegrass. The rates of Treflan in the greenhouse were 0.07 to 2.24 kg ai/ha (0.06 to 2.0 lb ai/A) and outdoors were 0.14 to 4.48 kg ai/ha (0.13 to 4.0 lb ai/A). Shoot fresh weights and visual estimates of percent control were determined 6 weeks after treatment (WAT). Percent control was also determined 3 WAT outdoors. In the greenhouse, approximately 1.0 kg ai/ha (0.89 lb ai/A) was necessary for control. Outdoors, less than 2.0 kg ai/ha (1.8 lb ai/A) was needed for control 3 WAT. However, 6 WAT, 2.6 and 3.4 kg ai/ha (2.3 and 3.0 lb ai/A) were required for control of perennial ryegrass and large crabgrass, respectively. Based on fresh weight reduction outdoors, even higher rates were necessary for control.

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* ‘Black-seeded Simpson’); oats (*Avena sativa* ‘Rodgers’).

Herbicides used in this study: Gallery (isoxaben) N-[3-(1-ethyl-1-methylpropyl)-5-isoxazolyl]-2,6-dimethoxybenzamide; Surflan (oryzalin) 4-(dipropylamino)-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 control. Production would be more profitable if hand weeding could be reduced. Aqueous herbicide concentrations necessary for weed control were determined for weeds common in container production. In addition, surface-applied Treflan rates necessary for grass control were approximately 1.0 kg ai/ha (0.9 lb ai/A) in the greenhouse and 3.0 kg ai/ha (2.7 lb ai/A) outdoors. These data can be applied to the development of an assay that can quickly and reliably detect these concentrations before weeds emerge and hand weeding is necessary. A rapid assay to determine when herbicides concentrations dissipate to ineffective levels could enable growers to better time herbicide applications and reduce hand weeding.

Introduction

Weeds can significantly reduce the growth of container nursery crops. Fretz (1972) reported that in 2.4-liter containers just one plant each of redroot pigweed and large crabgrass reduced the dry weight of Japanese holly by 47% and 60%, respectively. Berchielli-Robertson et al. (1987) reported that one plant each of prostrate spurge and eclipta were just as competitive as greater amounts of weeds. Craeger (1982) also reported that a combination of broadleaf and grass weeds reduced the plant size of cotoneaster, azalea, euonymus, pyracantha and holly.

Nursery growers rely heavily upon preemergence herbicides supplemented by hand weeding since few selective postemergence herbicides are available for safe broad-spectrum weed control. It is common practice in the southeastern U.S. for preemergence herbicides to be applied every 8 to 10 weeks during the growing season. After this time, herbicide concentrations have reached ineffective levels for weed control. Emerged weeds must be hand removed between herbicide applications, an expensive and laborious task. Gilliam et al. (1990) reported that depending on nursery size, annual hand weeding costs ranged 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 2.9 to 3.2 herbicide applications per year. More recently, it was reported in North Carolina that it costs up to \$1,367 to hand weed 1000 pots over a 4-month period with no herbicide applications, based on hourly wages of \$14.75, an average labor cost provided by several nurseries (Darden and Neal, 1999). If one applies these more current labor costs to the figures provided by Gilliam et al., the costs for supplemental hand weeding could range from \$2,389 to \$5,506 per hectare (\$967 to \$2,228 per acre).

The dominant weeds species in container-grown crops in the southeastern U.S. are mainly broadleaf weeds including hairy bittercress (*Cardamine hirsuta*), spotted spurge (*Euphorbia maculata*), eclipta (*Eclipta prostrata*) (Cross and Skroch, 1992; Derr, 1989). Annual grasses including large crabgrass (*Digitaria sanguinalis*) are also common (Singh et al., 1980; Wilcut et al., 1989). Research has shown that preemergence herbicides currently labeled in container nurseries are effective on these major problem weeds (Creager, 1982; Derr 1994; Gallitano and Skroch, 1993; Monaco and Hodges, 1974; Ruter and Glaze, 1992; Singh et al., 1980; Stamps and Neal, 1990; Weatherspoon and Currey, 1979; Wilcut et al., 1989). However, weeds continue to challenge nursery production efficiency.

Most herbicide applications in container nurseries contain a dinitroaniline herbicide. This family of herbicides provides a wide spectrum of annual grass and small-seeded broadleaf control (Stamps and Neal, 1990; Weber and Monaco, 1972;) and offers a broad range of crop tolerance (Neal et al., 1999). Usually they are prepackaged or tank-mixed with a more potent broadleaf herbicide to provide broad-spectrum annual grass and broadleaf preemergence control (Derr, 1994; Gallitano and Skroch, 1993; Neal and Senesac, 1991; Ruter and Glaze, 1992; Stamps and Neal, 1990; Whitwell and Kalmowitz, 1989).

Currently, the only way to know when herbicides have dissipated to ineffective levels is to wait for weed germination. If effective doses of preemergence herbicides could be predicted by a simple assay, growers could make more timely applications of herbicides; thus, reducing hand weeding. Based on this, the initial aim of this research was to develop a rapid assay system that nursery growers could use to quantitatively determine the herbicide concentration range present in container substrates and consequently know if they are at effective levels for weed control. However, effective concentrations for preemergence herbicides on common nursery weeds have not been determined. It was reported that isoxaben could effectively reduce radical growth of common grain cereal weeds by 50% at concentrations between 0.01 and 0.08 mg ai/L (Huggenberger and Ryan, 1985). Similar methods can be used to determine inhibitory concentrations of other nursery herbicides on important nursery weeds. These concentrations need to be correlated to surface-applied preemergence application rates necessary for weed control. Therefore, the objectives of this research were to 1) To determine the critical aqueous concentrations necessary for control of problem weeds with common herbicides of container nursery production and 2) To focus on trifluralin and determine surface-applied rates necessary for effective preemergence control of two sensitive grass species, large crabgrass and perennial ryegrass. These data can ultimately be correlated with trifluralin dissipation data in soilless nursery substrates and effective extractable concentrations for weed control (Chapter 2) to develop a predictive assay or model.

Materials and Methods

*Aqueous Concentration Response Experiments***.** Experiments were conducted to determine aqueous herbicide concentrations required for 80% control of common nursery weeds including eclipta, hairy bittercress, large crabgrass, and spotted spurge. In addition, two crop species were used, lettuce and oats, as potential bioassay species. Perennial ryegrass was also included in the Treflan experiment. Each experiment was conducted in a randomized complete block design with four replications, and was repeated. An experiment consisted of one herbicide, six plant species and six concentrations of a herbicide compared to a non-treated. Herbicides investigated included two dinitroanilines, Surflan 4 AS[1] [oryzalin; 480 grams active ingredient (ai) per liter (4 pounds ai per gallon) aqueous suspension] and Treflan 4 EC[1] [trifluralin; 480 grams ai per liter (4 pounds ai per gallon) emulsifiable concentrate]. Gallery 75 DF[1] (isoxaben; 75% ai dry flowable), mainly a broadleaf herbicide, was also included. The water solubility of Gallery, Surflan and Treflan are 1.0 mg/L, 2.6 mg/L, and 0.3 mg/L, respectively (Ahrens et al., 1994). Therefore, commercial formulations were used to facilitate suspension in water. Treatment solution concentrations were 0, 0.01, 0.05, 0.10, 0.50, 1.00 and 5.00 µg ai/mL.

Three Whatman #1 filter papers[2] 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 crop species were placed in petri dishes, each species in a separate dish. Petri dishes were wrapped with parafilm and incubated in a growth chamber receiving a photoperiod of 14 h at 24 C (75 F) and 10 h dark at 18 C (64 F). Plant shoot and root

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[1] Dow AgroSciences, 9330 Zionsville Rd., Indianapolis, IN 46268.

[2] Whatman Inc., 9 Bridgewell Place, Clifton NJ 07014.

growth were measured 5 to 9 days after initiation, depending upon the growth rate of each species. Average inhibition was calculated (expressed as a percent of the non-treated). Herbicide treatments did not have a significant effect on seed germination. Therefore, non-germinated seeds were not included in the average.

For purposes of analysis, data from both runs of each herbicide experiment were pooled. Percent inhibition data were subjected to analysis of variance and non-linear regression (Figures 1.1 – 1.5, Appendix figure A.1). Since data were compared to the non-treated, this rate was not included in the analyses. Rate responses were fitted to a non-linear model based on a Gompertz distribution described by Johnson and Kotz (1970) and shown in Equation 1. The upper asymptote was set at 100% control, assuming that with high enough rates, inhibition will reach 100%.

Equation 1.

$$Y = 100e^{-B * e^{-K * X}}$$

Where:

Y = root or shoot inhibition expressed as a percent

X = (Log_{10} + 3) of the herbicide concentration in µg ai/mL

B and K = estimated parameters describing the shape and steepness of the curve

Concentrations required to obtain 80% control (I_{80}) were estimated by solving Equation 2 for log concentration. Log concentration was then converted to actual concentration (µg ai/mL) by solving Equation 3. Log_{10} concentration equivalents are shown in Table 1.1.

Equation 2.

$$Logconcentration = -1/K \ln(0.22314/B) - 3$$

Equation 3.

$$Concentration = 10^{Logconcentration}$$

*Dose-Response Experiments***.** A preliminary test was conducted to determine Treflan dose-responses of the same weed and crop species used in the concentration response experiments. Percent control and shoot fresh weight reduction was determined 6 weeks after treatment (WAT). Across these two parameters, Treflan was not consistently effective on eclipta, hairy bittercress, spotted spurge, lettuce or oats (Appendix tables A.1 - A.5). However, it was effective on large crabgrass. Consequently, subsequent dose-response tests were conducted on large crabgrass and perennial ryegrass. Perennial ryegrass was chosen because it is another grass species with sensitivity to Treflan that germinates quickly, uniformly and is readily available.

The first run of the experiment with these two species was conducted in the greenhouse in 1.25 liter (0.3 gal) 15 cm (5.9 in) diameter plastic pots. The potting substrate was a bark plus sand mix (7:1 v/v) amended with 2.1 kg per m^3 (6 lbs per yd^3) pulverized dolomitic limestone and a slow release fertilizer[3], providing 0.525 kg per m^3 (1.5 lbs per yd^3) nitrogen, 0.06 kg per m^3 (0.17 lbs per yd^3) phosphorus, and 0.26 kg per m^3 (0.75 lbs per yd^3) potassium. Large crabgrass and perennial ryegrass were surface seeded. Herbicide application rates were 0, 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

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[3] Wilbro 15-4-9, Wilbro Inc., P.O. Box 400, Norway SC 29113.

sprayer with one TeeJet[4] 8001 even flat fan nozzle at a height of 31.8 cm (12.5 in) calibrated to deliver 187 liters per hectare (20 gallons per acre) at 241 kPa (35 PSI). Immediately following herbicide application pots were watered to incorporate the herbicide and reduce volatilization. Pots were watered once a day for the duration of the experiment. The experimental design was a randomized complete block with four replications. Percent control compared to the non-treated was visually evaluated 6 WAT. Shoot fresh weights were also measured and expressed as a percent of the non-treated.

The experiment was repeated outdoors under container production conditions with the following differences. Pot size was 11.4 L (3 gal) and 25 cm (10 in) diameter. Applications were made using a CO_2 pressurized backpack sprayer calibrated to deliver 280 liters per hectare (30 gallons per acre) at 276 kPa (40 PSI) equipped with two TeeJet 8003 flat fan nozzles. 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. Similarly, since we have observed that higher rates are required outdoors for control similar to that observed in greenhouse tests, the highest labeled rate for Treflan in container nurseries, 4.48 kg ai/ha (4.0 lbs ai/A), was added. Containers were irrigated following application and received approximately 2.5 cm (1 in) irrigation per day for the duration of the experiment. Evaluations were the same as in the greenhouse experiment except percent control was also determined 3 WAT.

Inhibition data (expressed as a percent of the non-treated) were subjected to analysis of variance and non-linear regression (Figures 1.6 – 1.8). Since data were compared to the non-treated, this rate was not included in the analyses. Rate responses were fitted to a non-

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[4] Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189-7900.

linear Logistic model described by Rawlings et al. (1988) shown in Equation 4. The upper asymptote was set at 100% control, assuming that with high enough rates; inhibition will reach 100%.

Equation 4.

$$Y = 100/1 + Be^{-K*X}$$

Where:

Y = Large crabgrass or perennial ryegrass inhibition expressed as a percent

X = Log_{10} of the herbicide application rate in kg ai/ha

B and K = estimated parameters describing the shape and steepness of the curve

Rates required to obtain 80% control (I_{80}) were estimated by solving Equation 5 for log rate. Log rate was then converted to rate (kg ai/ha) by solving Equation 6. Log_{10} rate equivalents are shown in Table 1.2.

Equation 5.

$$Lograte = -1/K \ln[(1.25-1)/B]$$

Equation 6.

$$Rate = 10^{Lograte}$$

Results and Discussion

Aqueous Concentration Response Experiments. Eighty-percent inhibition (I_{80}) values were determined for each species and herbicide combination (Table 1.3) based on the regression equations (Figures 1.1 - 1.5, Appendix figure A.1). The lower the I_{80} value, the more sensitive the species is to the herbicide because it requires a lower concentration to effectively reduce the root or shoot growth by 80%. Due to the high-extrapolated I_{80} values for Gallery and Surflan on oats, it was determined not to be a good bioassay species (Appendix table A.6). In these experiments, roots and shoots responded differently to each herbicide tested. Shoots of the three broadleaf weeds, eclipta, hairy bittercress and spotted spurge, had similar relative responses to the three herbicides. Based on I_{80} values, Gallery was the most effective, followed by Surflan and Treflan. For eclipta and hairy bittercress, the I_{80} values for Surflan and Treflan were beyond the range of concentrations tested, as well as for spotted spurge and Treflan. Thus, I_{80} values were extrapolated using the regression equation. Gallery is mainly a broadleaf herbicide (Pollak and Drinkall, 1993) 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 that Gallery had lower I_{80} values on the broadleaf weeds than did Treflan and Surflan, which are mainly grass herbicides. Gallery was most effective on hairy bittercress ($I_{80} = 0.4$ μg ai/mL), followed by spotted spurge ($I_{80} = 0.5$ μg ai/mL) and eclipta ($I_{80} = 1.3$ μg ai/mL) (Table 1.3). This ranking is similar to that seen in traditional herbicide efficacy trials. In outdoor container experiments, Gallery provided good control of hairy bittercress but was less effective on eclipta and spotted spurge (Judge and Neal, 2000). Of the three broadleaves, the lowest I_{80} value for Surflan was on spotted spurge ($I_{80} = 1.2$ μg ai/mL) (Table 1.3). Surflan can control spotted spurge (Derr, 1994; Judge and Neal, 2000; Weatherspoon and Currey, 1979), and has also been shown to provide moderate to good control hairy bittercress, but poor control of eclipta (Judge and Neal, 2000; Weatherspoon and Currey, 1979). Weatherspoon and Currey (1979) also reported that Treflan controlled hairy bittercress. This was at a rate of 5.6 kg ai/ha (5.0 lb ai/A), higher than the currently labeled rate. Judge and Neal (2000) showed that at a rate of 4.48 kg ai/ha (4.0 lb ai/A), Treflan does not control hairy bittercress. Gallery also provided substantial shoot reduction on lettuce (I_{80} = 1.6 μg ai/mL) (Table 1.3). Treflan and Surflan did not inhibit lettuce shoot growth within the range of concentrations tested and again I_{80} values were extrapolated.

For large crabgrass, the one annual grass species tested, results were quite different compared to the broadleaf species. Treflan was the most effective (I_{80} = 1.1 μg ai/mL) followed by Surflan (I_{80} = 1.2 μg ai/mL) and Gallery (I_{80} = 1.5 μg ai/mL) (Table 1.3). In this report, it was shown that Treflan could control large crabgrass at or below labeled rates (Table 1.4). Fretz (1973) also reported excellent control of large crabgrass with 4.48 kg ai/ha (4 lb ai/A). However, large crabgrass control with Treflan in containers is not always consistent. Judge and Neal (2000) reported that Treflan does not effectively control large crabgrass. The I_{80} value (I_{80} = 0.9 μg ai/mL) for perennial ryegrass was similar to large crabgrass. Surflan controlled large crabgrass in container experiments (Caviness et al., 1988; Judge and Neal, 2000; Wilcut et al., 1989). Gallery can have marginal activity on large crabgrass as well (Neal and Senesac, 1990). These reports may explain the similarities in observed I_{80} values across the three herbicides. In container production, 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.

Root responses in the petri dish cultures were not as consistent as the shoot responses, yet, trends were similar (Table 1.3). Gallery and Surflan (I_{80} = 0.4 μg ai/mL for both) provided similar inhibition of eclipta root growth followed by Treflan (I_{80} = 3.4 μg ai/mL) (Table 1.3). Gallery (I_{80} = 0.3 μg ai/mL) inhibited spotted spurge root growth at lower concentrations than Surflan (I_{80} = 1.4 μg ai/mL) or Treflan (I_{80} = 9.2 μg ai/mL). For hairy bittercress root inhibition, Surflan (I_{80} = 1.6 μg ai/mL) was most effective, followed by

Gallery (I_{80} = 3.9 µg ai/mL) and Treflan (I_{80} = 7.4 µg ai/mL, an extrapolated value) (Table 1.3). Perennial ryegrass had only a slightly higher I_{80} value for Treflan (I_{80} = 1.2 µg ai/mL) than large crabgrass. Large crabgrass root growth was most inhibited by Surflan (I_{80} = 0.1 µg ai/mL), followed by Gallery (I_{80} = 0.3 µg ai/mL) and Treflan (I_{80} = 0.5 µg ai/mL) (Table 1.3). Again, the similarity in response between herbicide concentrations is not usually seen in the field because use-rates of Gallery are much lower than those of Surflan and Treflan.

Dose-Response Experiments. Treflan dose-response data were fit to Logistic models (Figures 1.6 - 1.8). From the regression models, 80% inhibition (I_{80}) of large crabgrass and perennial ryegrass were determined for the preliminary greenhouse test, the greenhouse test and the outdoor Treflan dose-response test (Table 1.4). In the greenhouse, approximately 1.0 kg ai/ha (0.9 lb ai/A) was necessary for 80% control based on both percent control and fresh weight reduction data. Outdoors based on visual estimates of percent control; less than 2.0 kg ai/ha (1.8 lb ai/A) was needed for 80% control 3 WAT. However, 6 WAT, 2.6 and 3.4 kg ai/ha (2.3 and 3.0 lb ai/A) was required for control of perennial ryegrass and large crabgrass control, respectively. Higher rates were needed when 80% control was based on fresh weight reduction, 4.3 and 15.7 (an extrapolated value) kg ai/ha (3.8 and 14.0 lb ai/A) for large crabgrass and perennial ryegrass, respectively. Based on these data, preemergence control of sensitive grass species can be obtained with use-rates of container production. Additionally, since lower rates were required 3 WAT than 6 WAT, rapid Treflan losses are occurring during this time period.

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Table 1.1. Aqueous herbicide concentration (μg ai/mL) conversions to $\log_{10}$ concentrations (μg ai/mL).

Concentration (μg ai/mL)[a]	Log_{10} Concentration (μg ai/mL)[b]
0.01	-2.0
0.05	-1.3
0.10	-1.0
0.50	-0.3
1.00	0.0
5.00	0.7

[a] Concentrations of Gallery (isoxaben), Surflan (oryzalin) and Treflan (trifluralin) used in aqueous concentration response experiments conducted in petri dishes.

[b] Log_{10} concentrations were used for fitting regression curves (Figures 1.1 – 1.5, Appendix Figure A.1).

Table 1.2. Treflan (trifluralin) dose-response rate (kg ai/ha) conversions to $\log_{10}$ rates (kg ai/ha).

Rate (kg ai/ha)[a]	Log_{10} Rate (kg ai/ha)[b]
0.07[c]	-1.15
0.14	-0.85
0.28	-0.55
0.56	-0.25
1.12	0.05
2.24	0.35
4.48[d]	0.65

[a] Dose-response experiments were conducted in the greenhouse and outdoors to determine effective surface-applied rates necessary for preemergence control of large crabgrass and perennial ryegrass.

[b] Log_{10} rates were used for regression curves (Figures 1.6 – 1.8).

[c] Rate used in greenhouse experiment only.

[d] Rate used in outdoor experiment only.

Table 1.3. Aqueous concentrations of Gallery (isoxaben), Surflan (oryzalin) and Treflan (trifluralin) required for 80% inhibition (I_{80}) of root and shoot growth of eclipta (*Eclipta prostrata*), hairy bittercress (*Cardamine hirsuta*), spotted spurge (*Euphorbia maculata*), large crabgrass (*Digitaria sanguinalis*), perennial ryegrass (*Lolium perenne*) and lettuce (*Lactuca sativa*) as determined by petri dish assays. I_{80} values (n=8) determined from regression curves (Figures 1.1 – 1.5).

	Herbicide		
Species	Gallery	Surflan	Treflan
	μg ai/mL		
Shoot			
eclipta	1.3	9.8*	73.8*
hairy bittercress	0.4	5.9*	17.3*
spotted spurge	0.5	1.2	6.2*
large crabgrass	1.5	1.2	1.1
perennial ryegrass	n/a	n/a	0.9
lettuce	1.6	17.4*	7.2*
Root			
eclipta	0.4	0.4	3.4
hairy bittercress	3.9	1.6	7.4*
spotted spurge	0.3	1.4	9.2*
large crabgrass	0.3	0.1	0.5
perennial ryegrass	n/a	n/a	1.2
lettuce	0.1	0.6	8.4*

Table 1.4. 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. I_{80} values (n=4) were determined from regression curves (Figures 1.6 – 1.8) based on visual estimates of percent control and shoot fresh weight reduction (expressed as a percent of the non-treated).

	Large Crabgrass			Perennial Ryegrass	
	Preliminary Greenhouse	Greenhouse	Outdoors	Greenhouse	Outdoors
	kg ai/ha				
Percent control – 3 WAT[a]	n/a	n/a	1.88	n/a	1.54
Percent control – 6 WAT	0.84	1.08	3.42	1.03	2.58
Fresh weight – 6 WAT	0.54	0.86	4.28	0.74	15.71[b]

[a] Weeks after treatment

[b] Extrapolated value

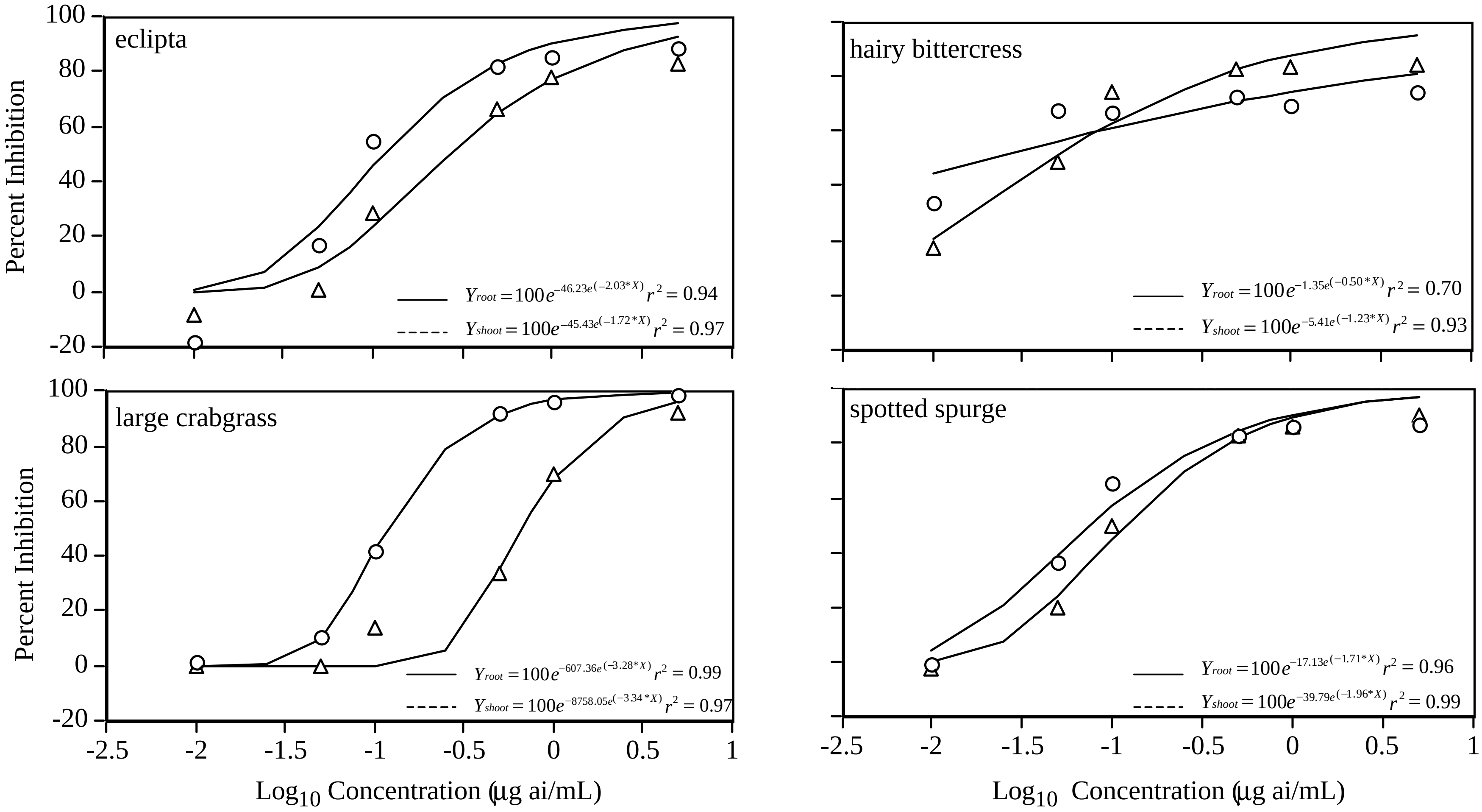


Figure 1.1. Inhibition (expressed as a percent of the non-treated) of root and shoot growth of eclipta, hairy bittercress, large crabgrass and spotted spurge by aqueous concentrations of Gallery (isoxaben). Response curves were fit to a Gompertz model: $Y = 100e^{-Be^{(-K*X)}}$ where K and B are estimated parameters and X is (Log_{10} + 3) of the herbicide concentration (µg ai/mL) (Table 1.1). Y_{root} is the predicted root inhibition curve (——) and Y_{shoot} is the predicted shoot inhibition curve (- - - -). Observed root inhibition means (n=8) are represented by (O) and shoot inhibition means (n=8) are represented by (Δ).

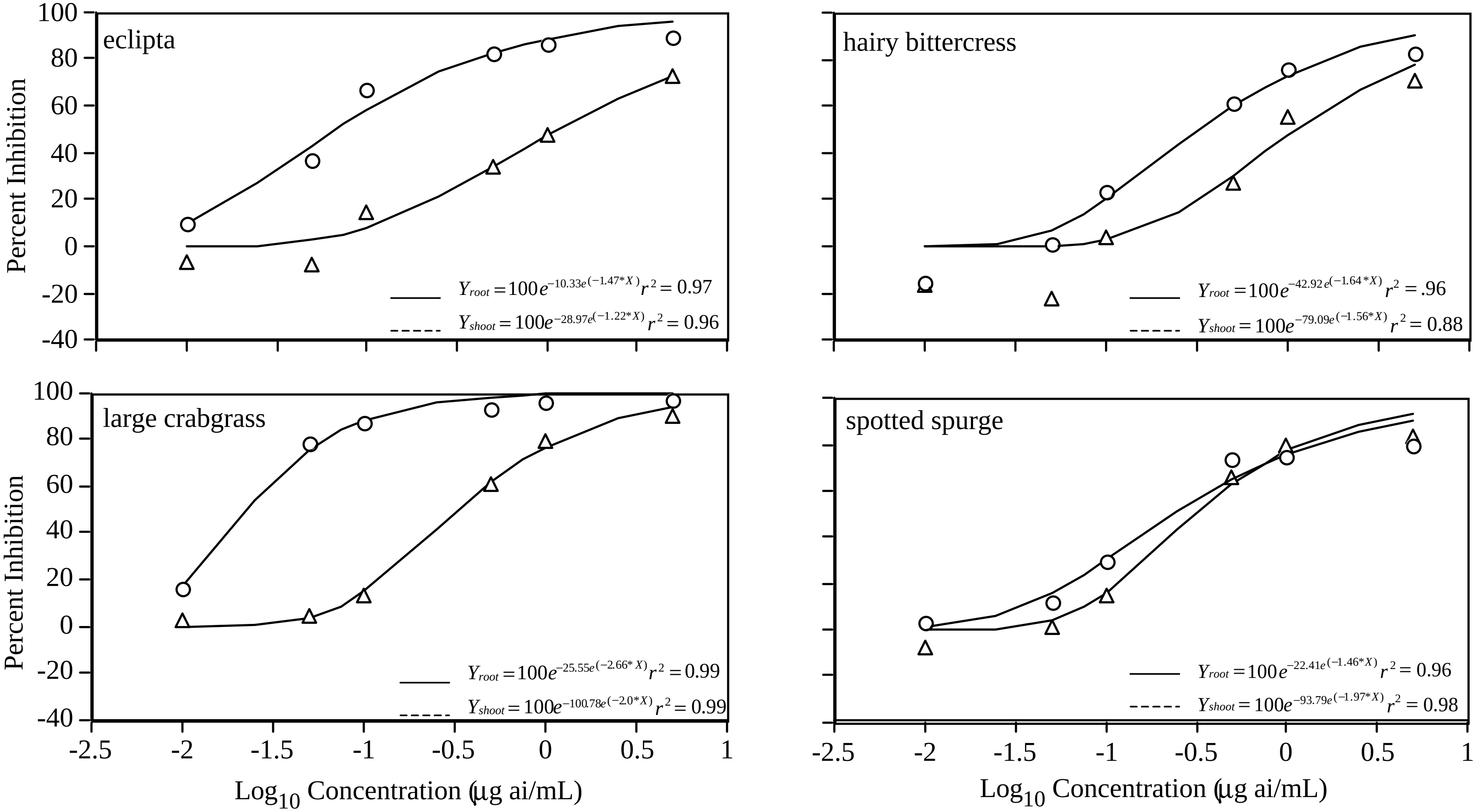


Figure 1.2. Inhibition (expressed as a percent of the non-treated) of root and shoot growth of eclipta, hairy bittercress, large crabgrass and spotted spurge by aqueous concentrations of Surflan (oryzalin). Inhibition response curves were fit to a Gompertz model: $Y = 100e^{-Be^{(-K*X)}}$ where K and B are estimated parameters and X is (Log_{10} + 3) of the herbicide concentration (µg ai/mL) (Table 1.1). Y_{root} is the predicted root inhibition curve (——) and Y_{shoot} is the predicted shoot inhibition curve (- - - -). Observed root inhibition means (n=8) are represented by (O) and shoot inhibition means (n=8) are represented by (Δ).

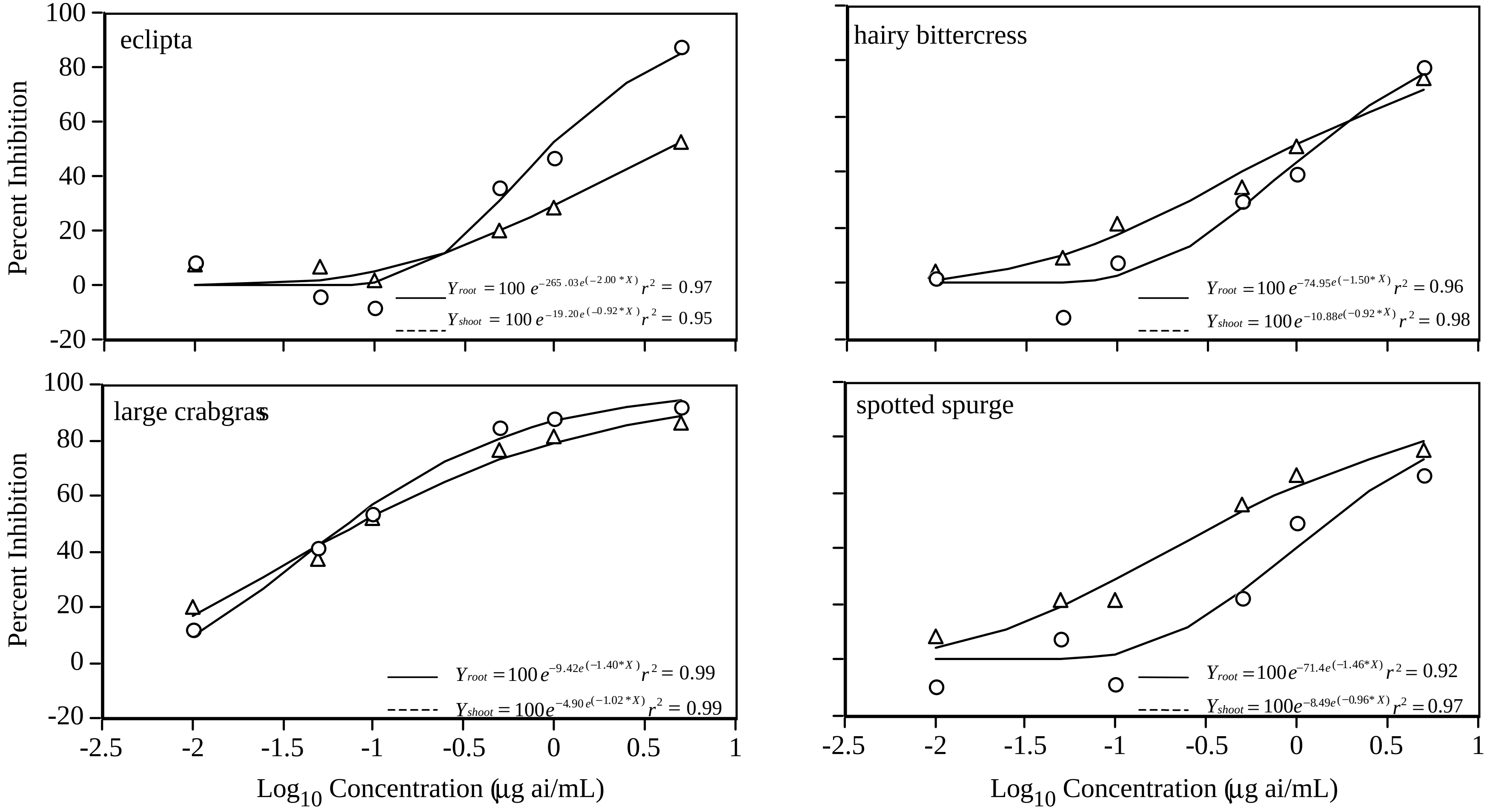


Figure 1.3. Inhibition (expressed as a percent of the non-treated) of root and shoot growth of eclipta, hairy bittercress, large crabgrass and spotted spurge by aqueous concentrations of Treflan (trifluralin). Response curves were fit to a Gompertz model: $Y = 100e^{-Be^{(-K*X)}}$ where K and B are estimated parameters and X is (Log_{10} + 3) of the herbicide concentration (µg ai/mL) (Table 1.1). Y_{root} is the predicted root inhibition curve (——) and Y_{shoot} is the predicted shoot inhibition curve (- - - -). Observed root inhibiton means (n=8) are represented by (O) and shoot inhibition means (n=8) are represented by (Δ).

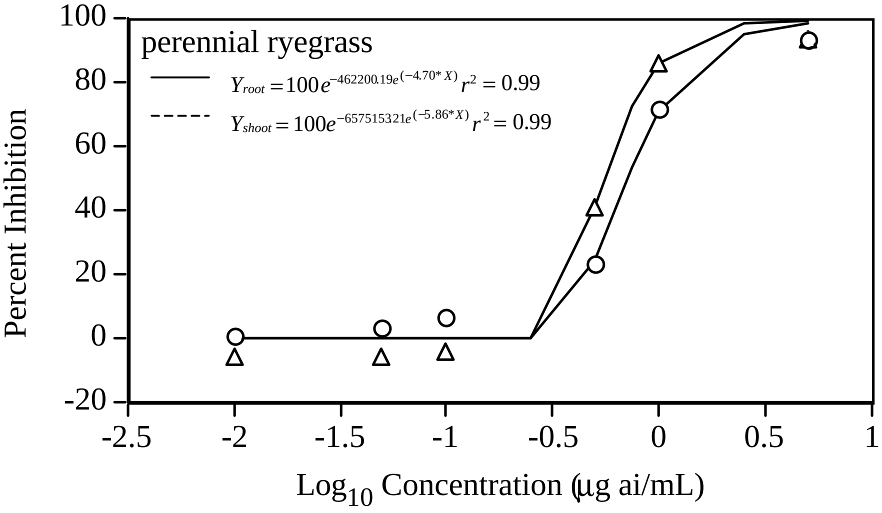


Figure 1.4. Inhibition (expressed as a percent of the non-treated) of root and shoot growth of perennial ryegrass by aqueous concentrations of Treflan (trifluralin). Response curves were fit to a Gompertz model: $Y = 100e^{-Be^{(-K*X)}}$ where K and B are estimated parameters and X is (Log_{10} + 3) of the herbicide concentration (μg ai/mL) (Table 1.1). Y_{root} is the predicted root inhibition curve (——) and Y_{shoot} is the predicted shoot inhibition curve (- - - -). Observed root inhibition means (n=8) are represented by (O) and shoot inhibition means (n=8) are represented by (Δ).

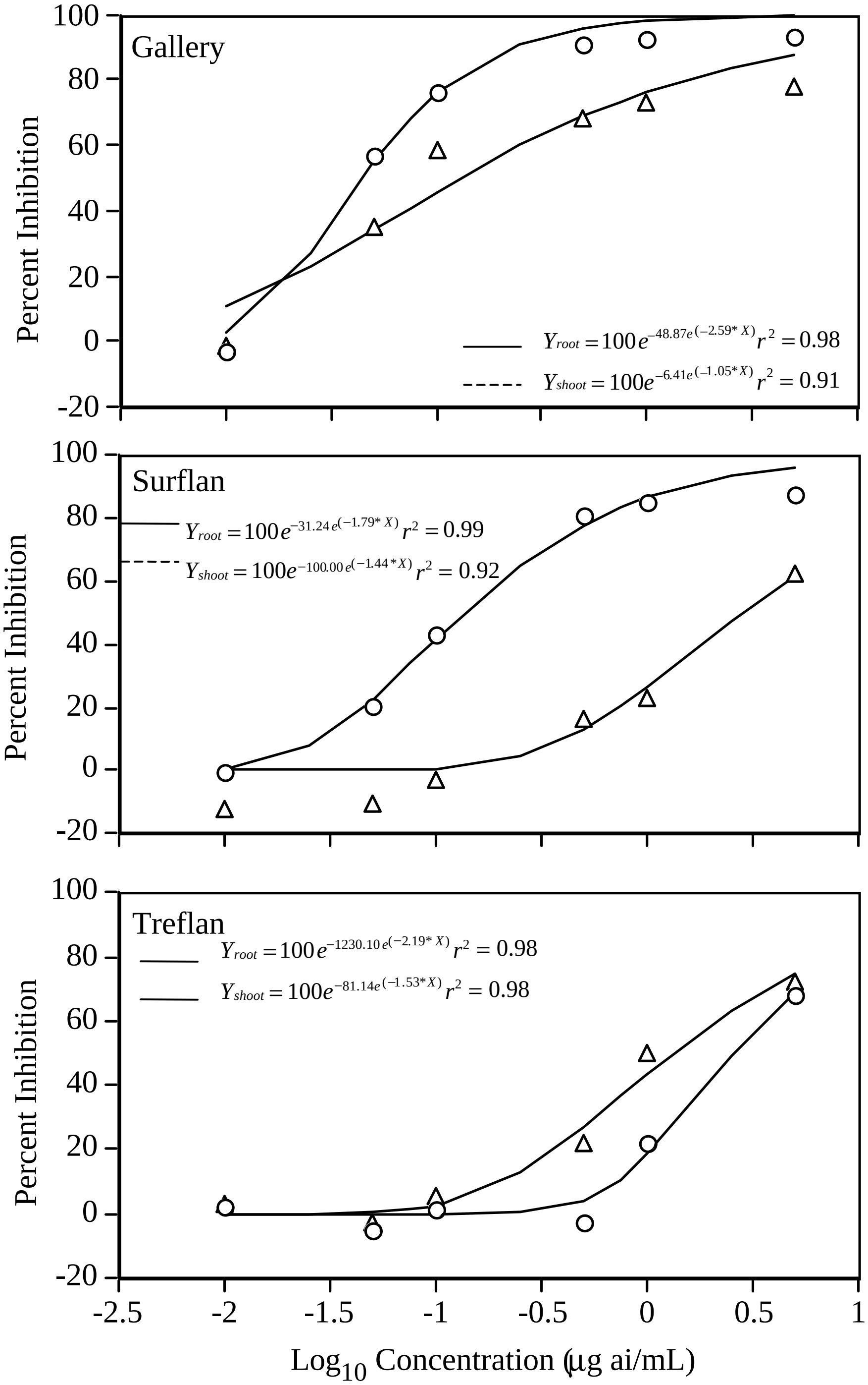
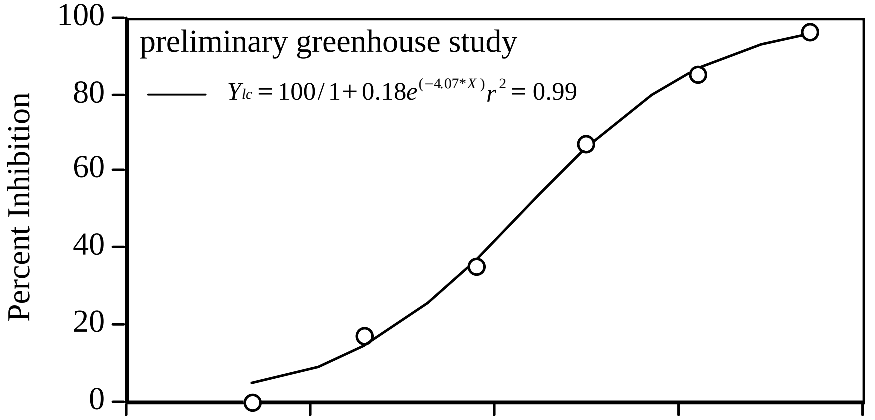
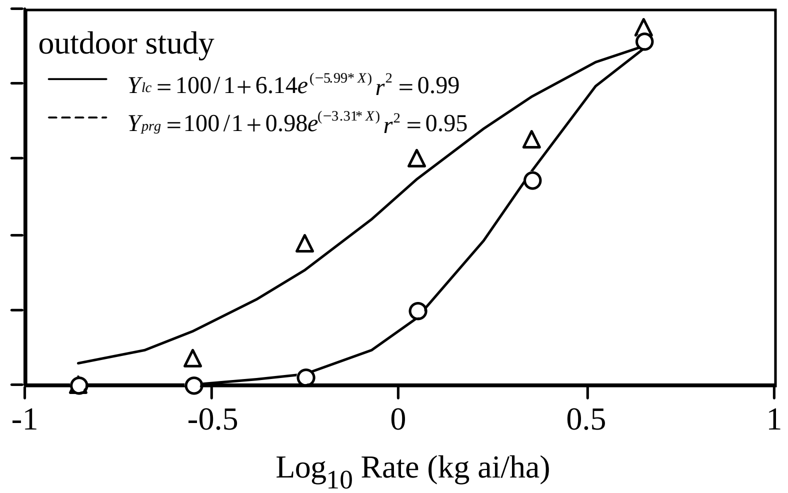


Figure 1.5. Inhibition (expressed as a percent of the non-treated) of root and shoot growth of lettuce by aqueous concentrations of Gallery (isoxaben), Surflan (oryzalin), and Treflan (trifluralin). Response curves were fit to a Gompertz model: $Y = 100e^{-Be^{(-K^*X)}}$ where K and B are estimated parameters and X is (Log_{10} + 3) of the herbicide concentration (µg ai/mL) (Table 1.1). Y_{root} is the predicted root inhibition curve (——) and Y_{shoot} is the predicted shoot inhibition curve (- - - -). Observed root inhibition means (n=8) are represented by (O) and shoot inhibition means (n=8) are represented by (Δ).





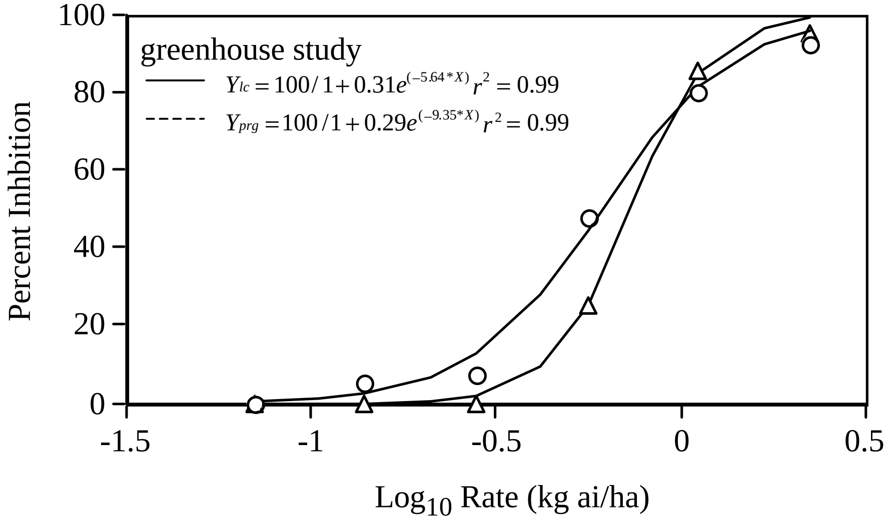


Figure 1.6. Response of large crabgrass and perennial ryegrass to Treflan (trifluralin) preemergence dose-response 6 weeks after treatment (based on visual estimates of percent inhibition). Response curves were fit to a Logistic model: $Y = 100/1 + Be^{(-K*X)}$ where K and B are estimated parameters and X is Log$_{10}$ of the herbicide rate (kg ai/ha) (Table 1.2). Y_{lc} is the predicted large crabgrass inhibition curve (——) and Y_{prg} is the predicted perennial ryegrass inhibition curve (- - - -). Observed large crabgrass inhibition means (n=4) are represented by (O) and perennial ryegrass inhibition means (n=4) are represented by (Δ).

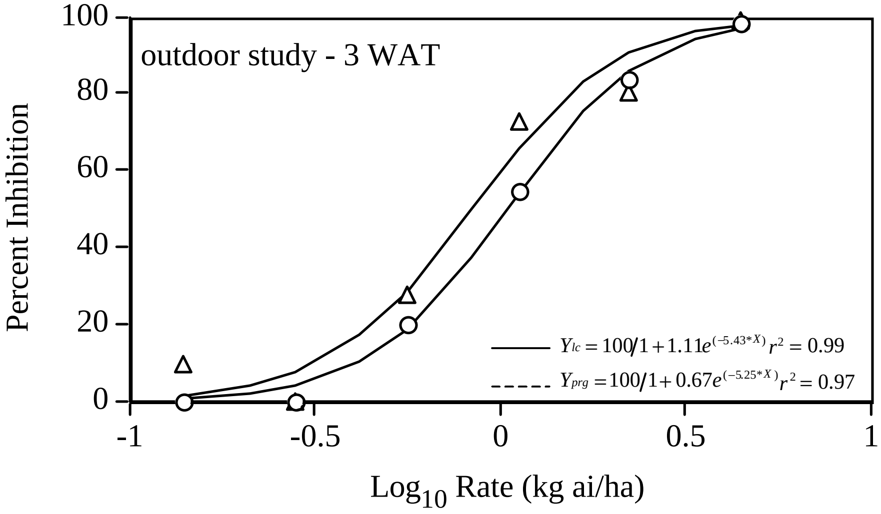


Figure 1.7. Response of large crabgrass and perennial ryegrass to Treflan (trifluralin) preemergence dose-response 3 weeks after treatment (WAT) (based on visual estimates of percent inhibition). Response curves were fit to a Logistic model: $Y = 100/1 + Be^{(-K*X)}$ where K and B are estimated parameters and X is Log_{10} of the herbicide rate (kg ai/ha) (Table 1.2). Y_{lc} is the predicted large crabgrass inhibition curve (——) and Y_{prg} is the predicted perennial ryegrass inhibition curve (- - - -). Observed large crabgrass inhibition means (n=4) are represented by (O) and perennial ryegrass inhibition means (n=4) are represented by (Δ).

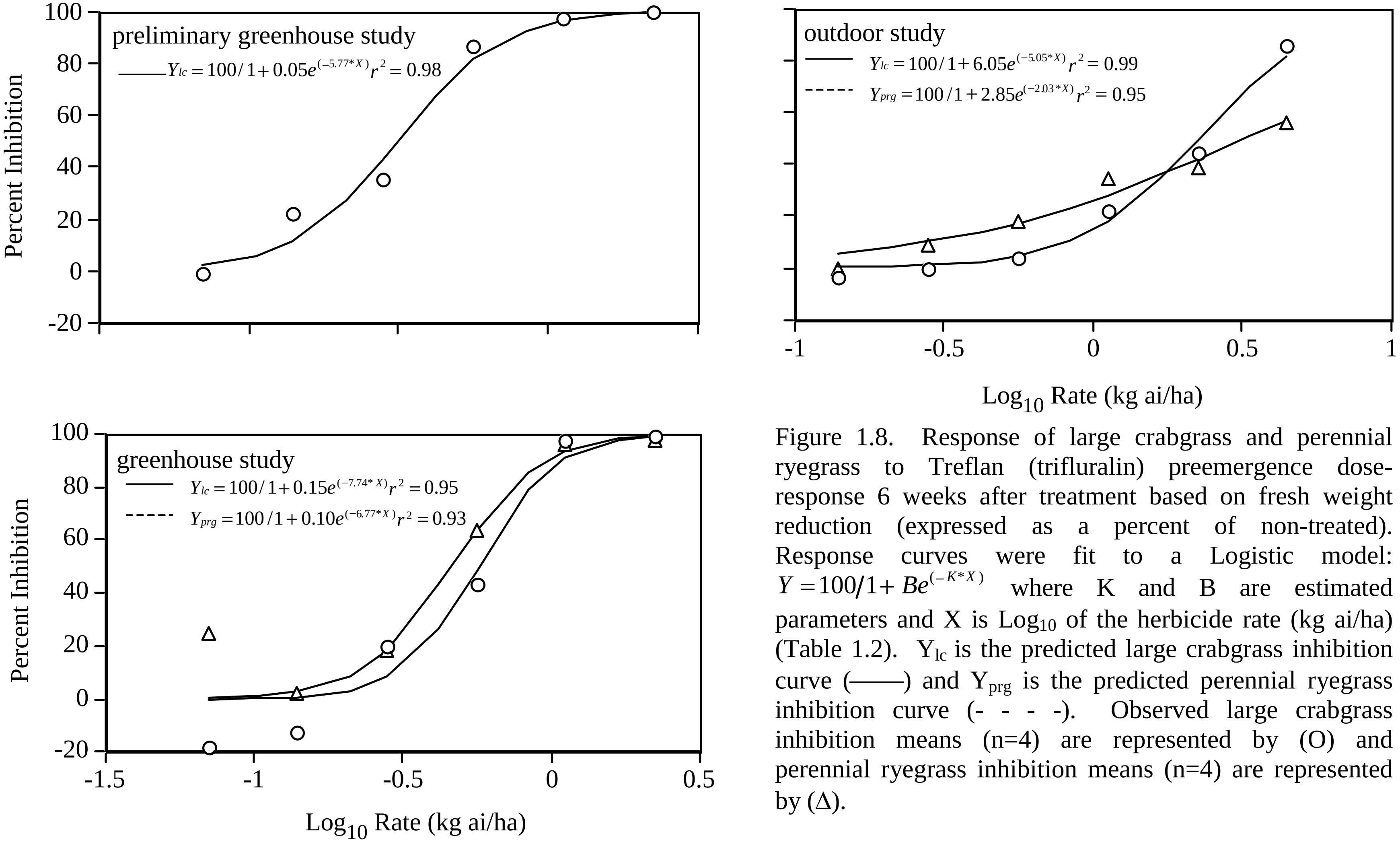


Figure 1.8. Response of large crabgrass and perennial ryegrass to Treflan (trifluralin) preemergence dose-response 6 weeks after treatment based on fresh weight reduction (expressed as a percent of non-treated). Response curves were fit to a Logistic model: $Y = 100/1 + Be^{(-K*X)}$ where K and B are estimated parameters and X is Log_{10} of the herbicide rate (kg ai/ha) (Table 1.2). Y_{lc} is the predicted large crabgrass inhibition curve (——) and Y_{prg} is the predicted perennial ryegrass inhibition curve (- - - -). Observed large crabgrass inhibition means (n=4) are represented by (O) and perennial ryegrass inhibition means (n=4) are represented by (Δ).

Chapter 2

Preen (trifluralin) Dissipation from the Surface Layer of a Soilless Plant Growth Substrate

(In the format appropriate for submission to Journal of Environmental Horticulture)

Preen (trifluralin) Dissipation from the Surface Layer of a Soilless Plant Growth Substrate[1]

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Abstract

In southeastern U.S. container nursery crop production, frequent applications of preemergence herbicides are relied upon for broad-spectrum weed control. An experiment was conducted to determine the dissipation of Preen (trifluralin) from the surface 2 cm (0.8 in) of a pine bark plus sand potting substrate and to compare these data with grass inhibition over time. The experiment was conducted at two locations during 2001. Large crabgrass (*Digitaria sanguinalis)* and perennial ryegrass (*Lolium perenne)* were seeded 0, 1, 2, 4, 6 and 8 weeks after treatment (WAT). Shoot and root growth were measured two weeks after seeding. Additionally, samples were taken from the top 2 cm (0.8 in) of the potting substrate 0, 1 and 3 days after treatment and 1, 2, 4, 6 and 8 WAT for laboratory analysis. Trifluralin was extracted from the potting substrate and quantified using gas chromatographic techniques. In the March to May trial, Preen lost effectiveness seven or more weeks after application, based on 50% weed growth, after which time weeds emerged and flourished. In the May to July trial, however, Preen lost effectiveness much sooner, between two and seven weeks after application, depending on species. Preen residues in the surface of the potting substrate decrease rapidly after application and slowly thereafter reaching what may be considered critically low levels approximately 4 to 6 weeks after application. These results suggest that for trifluralin, the common reapplication interval of 8 to 10 weeks in the southeastern U.S. may need to be shortened to 4 to 6 weeks, during months of high temperatures.

Index Words: herbicide dissipation, container nursery production, herbicides, large crabgrass.

Species used in this study: large crabgrass [*Digitaria sanguinalis* (L.) Scop.]; perennial ryegrass (*Lolium perenne* L.).

Herbicides used in this study: Preen (trifluralin) 2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine.

Significance to the Nursery Industry

Trifluralin is the grass control component of the preemergence herbicide Snapshot TG (trifluralin + isoxaben, for broadleaf weed control). In the southeastern U.S., during the warmer months of the growing season, trifluralin dissipates quickly. Its half-life is 5 days, and 20% growth of both large crabgrass and perennial ryegrass occurs in less than three weeks. It takes 2 to 7 weeks to reach 50% growth of these same species. The current trifluralin reapplication interval of 8 to 10 weeks may need to be shortened to 4 to 6 weeks during the growing season to improve performance of preemergence herbicides and reduce the need for hand weeding.

Introduction

In container nursery crop production systems in the southeastern U.S., the most common substrate is a soilless pine bark based mix (Wehtje et al., 1993). Due to the lack of selective postemergence herbicides available for broad-spectrum weed control, frequent applications (every 8 to 10 weeks) of preemergence herbicides are relied upon for broad-spectrum weed control. Most preemergence herbicide programs include dinitroaniline (DNA) herbicides such as trifluralin, pendimethalin, oryzalin or prodiamine. This family of herbicides offers a broad range of crop tolerance (Neal et al., 1999) and provides a wide spectrum of annual grass and some small-seeded broadleaf weed control (Stamps and Neal, 1990; Weber and Monaco, 1972). Often, DNA herbicides are pre-packaged or tank-mixed with more effective broadleaf herbicides to achieve broad-spectrum weed control (Derr, 1994; Gallitano and Skroch, 1993; Neal and Senesac, 1991; Ruter and Glaze, 1992; Stamps and Neal, 1990; Whitwell and Kalmowitz, 1989).

Despite frequent herbicide applications during the growing season, herbicides often lose their effectiveness before re-application. As a result, weeds that germinate between herbicide applications are removed by hand, an expensive and laborious task. Gilliam et al. (1990) reported that depending on nursery size, annual hand weeding costs ranged 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 2.9 to 3.2 herbicide applications per year. More recently, it was reported in North Carolina that, when no herbicides are used, it cost up to \$1,367 to hand weed 1000 pots over a 4-month period, based on hourly wages of \$14.75, an average of labor cost provided by several local nurseries (Darden and Neal, 1999). If one applies these more current labor costs to the figures provided by Gilliam et al., the cost for supplemental hand weeding would range from \$2,389 to \$5,506 per hectare (\$967 to \$2,228 per acre).

Snapshot TG[1] is commonly used in container nursery production for broad-spectrum preemergence weed control. It consists of the dinitroaniline, trifluralin, for grass control and isoxaben for broadleaf weed control. Trifluralin was the first of the dinitroaniline herbicides to be registered in 1963 (Weber, 1990). Trifluralin has a very low water solubility of 0.3 μg/mL (Ahrens et al., 1994), but is readily soluble in organic solvents (Tepe and Scroggs, 1967). It is susceptible to decomposition by ultraviolet irradiation (Tepe and Scroggs, 1967) and has a high vapor pressure that causes volatilization (Weber and Monaco, 1972; Weber, 1990). In agronomic crop production, Treflan (trifluralin) is often soil incorporated to reduce

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[1] Dow AgroSciences, 9330 Zionsville Rd., Indianapolis, IN 46268.

volatilization; however, in container nursery production, this is not feasible. Therefore, a granular formulation is often used either as Preen, Trifluralin 5G or Snapshot TG. Volatilization is reduced if irrigation follows shortly after application especially during high temperature months. Trifluralin is strongly sorbed to soil especially organic, lipophilic, and/or proteinaceous substances (Weber, 1990). In a review of dinitroanilines, trifluralin half-life values ranged from 19 to 132 days in various field trials (Weber, 1990). While trifluralin persistence has been reported for many field soils, no data are available on the half-life of trifluralin in irrigated soilless nursery substrates. Based on the need for frequent re-application to maintain acceptable weed control, it is likely that the half-life in the surface of soilless substrates is less than those observed in field soils.

With these properties in mind, an experiment was conducted to analytically determine trifluralin dissipation over time in a soilless substrate system and to compare grass inhibition over the same time period. By quantifying dissipation of one component of a standard nursery herbicide, it is hoped that one might be able to estimate the dissipation of the prepackaged product and better predict when herbicide re-application is necessary.

Materials and Methods

General Methods. Plastic containers 11.4 L (3 gal), 25.4 cm (10 in) in diameter, were filled with a pine bark plus sand substrate (7:1 v/v) amended with 2.1 kg per m^3 (6 lbs per yd^3) pulverized dolomitic limestone and a slow release fertilizer[2], providing 0.525 kg per m^3 (1.5 lbs per yd^3) nitrogen, 0.06 kg per m^3 (0.17 lbs per yd^3) phosphorus, and 0.26 kg per m^3 (0.75 lbs per yd^3) potassium. Preen 1.47G[3] [trifluralin, 1.47% active ingredient (ai) granule]

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[2] Wilbro 15-4-9, Wilbro Inc., P.O. Box 400, Norway SC 29113.

[3] Greenview, a division of Lebanon Seaboard Corp., 1600 E. Cumberland St., Lebanon, PA 17042.

was applied at 4.48 kg ai/ha (4.0 lbs ai/A) using a handheld shaker jar and compared to a non-treated. The experiment was conducted at two locations. The first test was initiated on March 28, 2001 and conducted at the Horticultural Field Laboratory in Raleigh, North Carolina. The second test was initiated on May 17, 2001 and conducted at the Horticultural Crops Research Station in Castle Hayne, North Carolina. The experimental design for each test was a randomized complete block with four replications. Irrigation at approximately 2.5 cm (1 in) was applied each day at each location. Rainfall data are shown in Figure 2.1

Herbicide Dissipation Methods. Potting substrate samples were removed from different pots in the same plot 0 (after irrigation), 1, and 3 days after treatment and 1, 2, 4, 6 and 8 weeks after treatment (WAT). Samples were taken from the top 2 cm (0.8 in) of the substrate by placing a cardboard frame inside the perimeter of the pot to allow the sample to be taken only from the interior 21.6 cm (8.5 in) diameter center. Each sample was placed in a sealed plastic bag and stored in a freezer at –12 C (10 F) until laboratory analysis. The top 2 cm (0.8 in) of substrate was chosen as the sampling region because the majority of small-seeded grasses germinate in this region (Anderson, 1983); thus, the herbicide forms the chemical barrier necessary in this region to inhibit root and shoot growth of germinating weed seedlings. Losses from volatilization and / or leaching were not quantified because once they have left the surface layer of the substrate, they do not contribute to weed control.

Samples were extracted according to methods described by Tepe and Scroggs (1967) and Garcia-Valcarcel et al. (1996) with some modifications. Ten grams of potting substrate were tared into a Soxhlet thimble and extracted for 4 hours with 225 mL of hexane:acetone (1:1) (v/v) at 6 turnovers per hour. Extracts were concentrated to 2 to 3 mL by rotary evaporation at 40 C (104 F) and brought to 10 mL with hexane. Samples were transferred to a glass column [30.5 by 1.25 internal diameter (i.d.) –cm, (12 by 0.5 in)] containing 10 g of 6% deactivated Florisil topped with 2.5 cm $Na_2SO_{4(anhyd.)}$ pre-rinsed with 25 mL of hexane. Trifluralin was eluted with 100 mL of hexane:acetone (97:3) (v/v) and concentrated to 2 to 3 mL by rotary evaporation at 40 C (104 F). Samples were diluted with hexane and transferred to gas chromatography vials.

Residue levels were quantified on a dry weight basis using a Varian[4] Model 3400 Gas Chromatograph equipped with a Thermionic Specific Detector (TSD), Model 8200CX Autosampler and Varian Star data system. The column was a 30 m (98 ft) by 0.53 mm (0.02 in) (i.d.) fused silica DB-35[5]. Helium was the carrier gas at a flow rate of 6.1 mL/min. Gases to the detector were H_2, air and He (make up gas) at flow rates of 4.03, 169.15 and 22.35 mL/min, respectively. Temperatures were 175 C (347 F) for the inlet and 300 C (572 F) for the detector. A temperature program was run as follows: 150 C (302 F), hold 2 minutes; to 215 C (419 F) at 10 C (50 F) per minute, hold 2 minutes; to 290 C (554 F) at 15 C (58 F) per minute, hold 2 minutes. Injections were made in the splitless mode. The retention time of trifluralin was 5.8 minutes.

Concentrations are reported as μg trifluralin per g dry weight of potting substrate. Data were subjected to analysis of variance. A significant run by treatment effect was present. Therefore, data will be presented individually for each experimental run. Data were then subjected to non-linear regression (Figure 2.2) based on a Weibull model described by Rawlings (1988) shown in Equations 1 and 2.

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[4] Varian, Inc., 2700 Mitchell Dr., Walnut Creek, CA 94598.

[5] J&W Scientific, Inc., 91 Blue Ravine Rd., Folsom, CA 95630-4714.

Equation 1 (run 1).

$$Y = A + (0.05 + (1 - 0.05e)^{-(X/\sigma)^{C}}$$

Equation 2 (run 2).

$$Y = A + e^{-(X/\sigma)^{C}}$$

Where:

Y = trifluralin concentration (μg trifluralin/g dry weight of substrate)

X = sampling date (expressed as days after treatment)

A, C, and σ = estimated parameters describing the shape of the curve

Bioassay Methods. Concurrent with sampling of the potting substrate, containers were also surface seeded with large crabgrass and perennial ryegrass. Two additional experiments were included in this portion of the research. A second experiment in Raleigh was initiated on June 12, 2001 and a second experiment in Castle Hayne was initiated on June 18, 2001, for a total of four runs of the experiment. One pot per plot was half seeded with each grass species 0, 1, 2, 4, 6, and 8 WAT. Shoot and root growth of 10 randomly selected plants of each species was measured 2 weeks after seeding and data are expressed as percent of the non-treated. Each run of the experiment is presented separately. Data were subjected to analysis of variance and fitted to non-linear regression curves (Figures 2.4 and 2.5) based on the Weibull model shown in Equation 3.

Equation 3.

$$Y = A + e^{-(X/\sigma)^{C}}$$

Where:

Y = shoot or root percent inhibition

X = date that plants were seeded, expressed as days after treatment

A, C, and σ = estimated parameters describing the shape of the curve

Concentrations at which 20% (GR_{20}) and 50% (GR_{50}) growth occurred were estimated by solving equations 4 and 5, respectively.

Equation 4.

$$GR_{20} = \sigma * 0.2231^{1/C}$$

Equation 5.

$$GR_{50} = \sigma * 0.6931^{1/C}$$

Results and Discussion

A significant difference in trifluralin concentrations was observed between the two dissipation experiments (Figure 2.2). Trifluralin concentrations in Raleigh were higher at the onset of the study and remained higher throughout than in the Castle Hayne study, conducted more than 1.5 months later. The concentration at day zero, just after irrigation for the Raleigh test, was 174 µg/g and at Castle Hayne was 35 µg/g. These concentrations are not accounted for in the regression curve, but the difference is striking. The differences in overall concentrations between the two tests are most likely temperature and water dependent. Irrigation was similar in both experiments, but rainfall varied (Figure 2.1). The Raleigh test was conducted earlier in the growing season (March to May) than the Castle Hayne test (May to July). Mean temperatures for the day of application were 24 C (75 F) at Castle Hayne and 3 C (37 F) at Raleigh and remained between 4 and 18 C (39 and 64 F) for the first week of the experiment (Figure 2.3). Trifluralin vapor losses are greater with increased temperature and moisture (Weber, 1990; Laabs et al., 2000). It is very unlikely that losses were due to leaching because of its low water solubility (Peter and Weber, 1985). In an Oxisol soil, after 28 days, only 0.07% of trifluralin was detected below 15 cm (6 in) soil depth (Laabs et al., 2000). In container production with a soilless substrate, less than 1% of applied trifluralin was detected in runoff water within 5 days after treatment and decreased to below the detection limit by 14 DAT (Wilson et al, 1996). In the second year of the same experiment, no trifluralin residues were detected in pond water. Therefore, rapid losses of trifluralin and lower concentrations in the second run of the study (Castle Hayne) are presumed to be primarily due to volatilization. Rates of dissipation of trifluralin over time were similar in both studies. Dissipation was rapid within the first week and slowly thereafter, beginning to level off about three weeks after application.

Dissipation of herbicides in soil is dependent upon the physiochemical properties of the herbicides and environmental conditions. The half-life of trifluralin in the Raleigh test was less than 1 day, while at Castle Hayne it was 5 days. In a review of dinitroanilines, it was reported that the half-life values of trifluralin ranged from 19 to 132 days in various field trials (Weber, 1990). According to Ahrens et al. (1994), the average half-life of trifluralin in the field on most soils is 45 days with less than 10% remaining one year after application. They also report that half-life is longer in cool, dry areas (Ahrens et al., 1994). Laabs et al. (2000) reported a dissipation half-life of trifluralin to be less than 1 day in a Brazilian tropical region and attributed the fast initial disappearance to chemical and microbial degradation, volatilization and physical losses. These losses occurred more rapidly, however, than reports from more temperate regions. While examining herbicide dissipation in a Haploxeralf soil in South Australian vineyards, Ying and Williams (2000) reported a fast initial loss of trifluralin followed by slow subsequent degradation. Trifluralin half-life in these soils and climate varied from 27 to 30 days. It appears to be consistent with losses from container substrates as well.

Days until 20% growth ($GR_{20,}$ equivalent to 80% inhibition) and subsequently 50% growth ($GR_{50,}$ equivalent to 50% inhibition) growth, compared to the non-treated, were determined from regression curves (Figures 2.4 and 2.5). These data were significantly different in each experiment (Tables 2.1 and 2.2). In the March to May, Raleigh experiment, it took 37 days to reach 20% large crabgrass shoot growth, while root growth did not achieve 20% growth during the entire experiment. Perennial ryegrass took nearly 40 days to reach 20% root and shoot growth, and 41 days for shoot growth to reach 50%. Perennial ryegrass root growth did not reach 50% during the study (Table 2.1). In the May to July and June to August experiments (Castle Hayne, run 1; Raleigh run 2; and Castle Hayne, run 2), results were quite different (Table 2.2). Large crabgrass 20% growth occurred in 6 to 21 days, and 29 to 53 days for 50% growth. For perennial ryegrass, 20% growth occurred in less than seven days. Eleven to 35 days were required for 50% perennial ryegrass growth (Tables 2.1 and 2.2).

Despite the differences in days to reach varying levels of growth through the herbicide barrier, inhibitory concentrations were quite similar (Table 2.1). For example, 20% large crabgrass root growth occurred when trifluralin concentrations were 12.5 and 15 μg/g for the Raleigh and Castle Hayne runs, respectively. For 50% large crabgrass root growth, concentrations were 4.1 and 10.3 μg/g. Similarly, for 20% large crabgrass shoot growth, concentrations were 13.4 and 18.1 μg/g, and for 50% growth concentrations were 3.8 and 13.4 μg/g, respectively. For 20% perennial ryegrass root growth trifluralin concentrations were 15.0 and 17.7 μg/g, and for 50% root growth concentrations were 3.4 and 14.7 μg/g, respectively. For 20% perennial ryegrass shoot growth concentrations were 17.5 and 23.2 μg/g, and for 50% shoot growth concentrations were 7.0 and 17.3 μg/g, respectively (Table 2.1).

In the southeastern U.S., during the warmer months of the growing season, trifluralin dissipates quickly. Its half-life is 5 days, and 20% growth of both large crabgrass and perennial ryegrass occurs in one to three weeks, while 50% growth occurs within 7 weeks. The current herbicide application intervals of 8 to 10 weeks may need to be shortened to improve the performance of preemergence herbicides and reduce the need for hand weeding, particularly during the summer months.

Based on this information, another option to improve herbicide performance might be to apply lower rates of trifluralin more frequently. This option may maintain adequate concentrations for weed control without the initial loss of trifluralin. Neal[6] found this approach to be equally or more effective with Surflan (oryzalin) and Gallery (isoxaben). Also, another way to utilize this information would be the development of slow-release nursery herbicides. Fain et al. (2001) have reported this type of research with oryzalin. For such strategies or formulations, herbicide applicators or formulation release rates will need to target the maintenance of trifluralin concentrations to be greater than 23 μg/g, the highest concentration where weeds were no longer controlled.

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[6] Neal, Joe; Personal communication, unpublished data, 2001.

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Table 2.1. Days to 20% (GR_{20}) and 50% (GR_{50}) large crabgrass (*Digitaria sanguinalis*) and perennial ryegrass (*Lolium perenne*) growth in outdoor container dissipation studies and the corresponding Preen (trifluralin) concentration in the upper 2 cm (0.8 in) of the potting substrate at that point in time (as determined by extraction and gas chromatography quantification).

			20% Growth		50% Growth	
Species	Location[a]	Plant Part[b]	GR_{20}[c]	Trifluralin Concentration[d]	GR_{50}[c]	Trifluralin Concentration[d]
			(days)	(μg/g)	(days)	(μg/g)
Large crabgrass	Raleigh	Root	90	12.5	167	10.3
	Castle Hayne	Root	6	15.0	29	4.1
	Raleigh	Shoot	37	18.1	74	13.4
	Castle Hayne	Shoot	7	13.4	31	3.8
Perennial ryegrass	Raleigh	Root	39	17.7	59	14.7
	Castle Hayne	Root	6	15.0	35	3.4
	Raleigh	Shoot	40	17.5	41	17.3
	Castle Hayne	Shoot	3	23.2	16	7.0

[a] Raleigh, NC - experiment March to May; Castle Hayne, NC – experiment May to July.
[b] Ten root and shoot growth measurements were taken and expressed as a percent of the non-treated.
[c] Days to 20% and 50% root and shoot growth were calculated using regression equations shown in Figures 2.4 and 2.5.
[d] Pots were treated initially with Preen (trifluralin) at 4.48 kg ai/ha (4.0 lb ai/A).

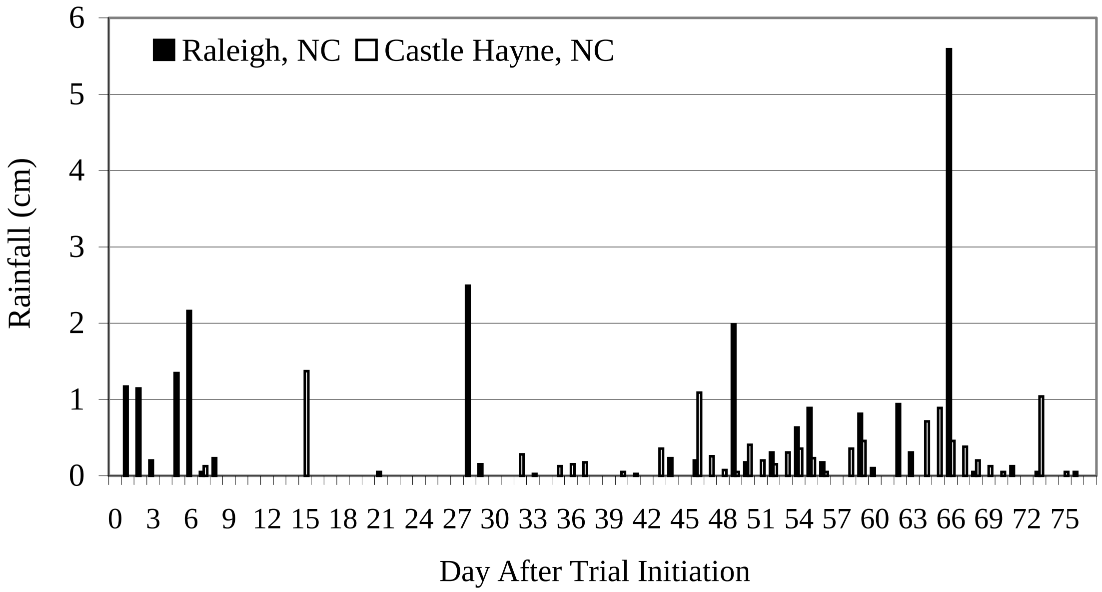
Table 2.2. Days to 20% (GR_{20}) and 50% (GR_{50}) growth of large crabgrass (*Digitaria sanguinalis*) and perennial ryegrass (*Lolium perenne*) in outdoor container dissipation experiments. Pots were treated with Preen (trifluralin) at 4.48 kg ai/ha (4.0 lb ai/A).

Species	Location[a]	Part[b]	GR_{20}[c]	GR_{50}[c]
			days	days
Large crabgrass	Raleigh (run 2)	Root	21	50
	Castle Hayne (run 2)	Root	8	39
	Raleigh (run 2)	Shoot	17	46
	Castle Hayne (run 2)	Shoot	9	53
Perennial ryegrass	Raleigh (run 2)	Root	5	16
	Castle Hayne (run 2)	Root	7	17
	Raleigh (run 2)	Shoot	4	11
	Castle Hayne (run 2)	Shoot	4	11

[a] Raleigh, NC - experiment June - August, Castle Hayne, NC – experiment June - August.

[b] Ten root and shoot growth measurements were taken and expressed as a percent of the non-treated.

[c] Days to 20% and 50% root and shoot growth were calculated using regression equations in Figures 2.4 and 2.5.



Raleigh (March)-------------------------(April)-------------------------(May)------------------

Castle (May)------------------------------(June)---------------------------(July)------------------
Hayne

Figure 2.1. Daily rainfall during Preen (trifluralin) dissipation studies at Raleigh, NC and Castle Hayne, NC. Each location also received daily overhead irrigation (approximately 2.5 cm (1 in)).

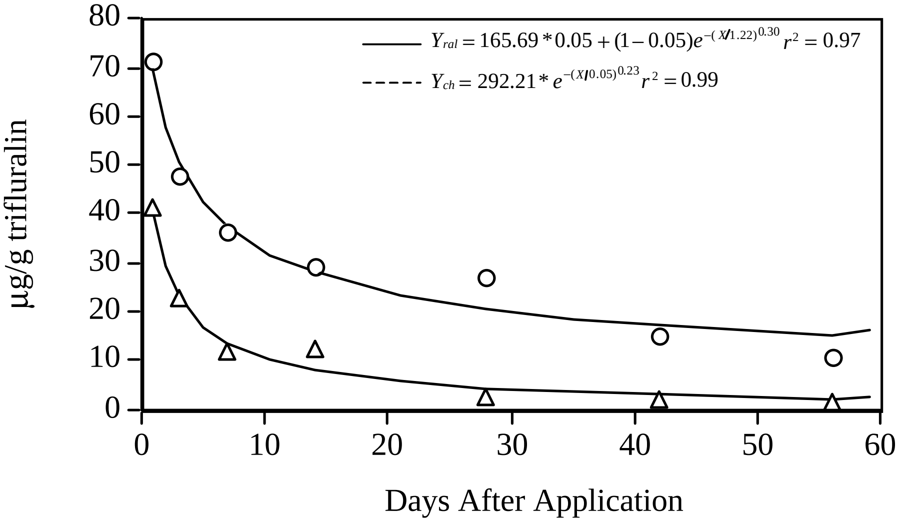
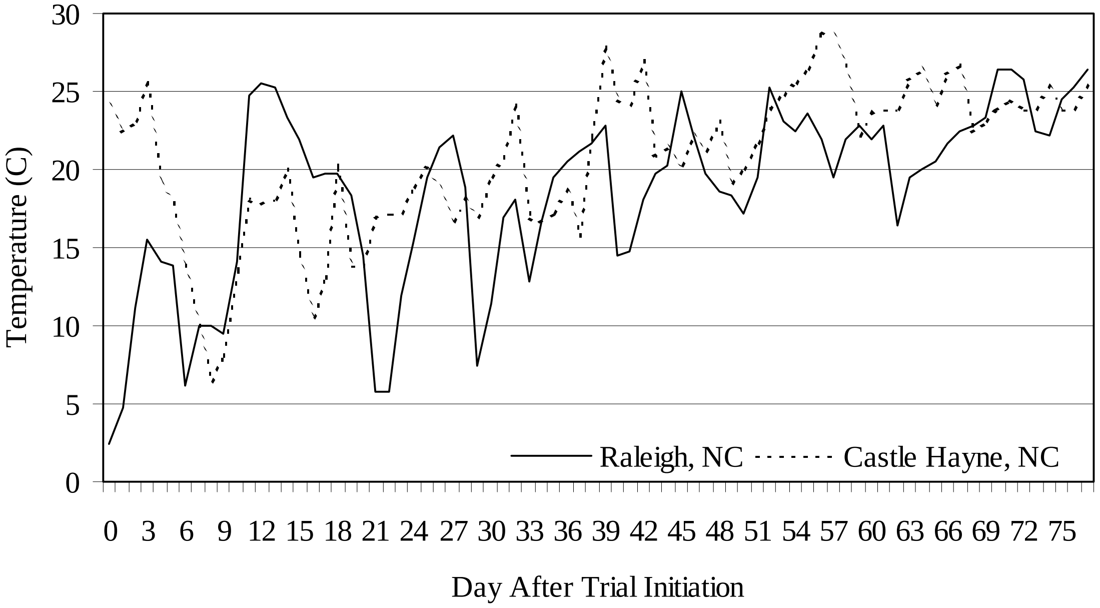


Figure 2.2. Trifluralin (Preen) dissipation curves in a soilless nursery substrate (pine bark plus sand (7:1 v/v)). Dissipation data were fit to a Weibull model: $Y = A + e^{-(X/\sigma)^C}$ where A, C, and σ are estimated parameters and X is days after treatment. Y_{ral} is the predicted Raleigh, NC dissipation curve (——) and Y_{ch} is the predicted Castle Hayne, NC dissipation curve (- - - -). Observed Raleigh concentration means (n=4) are represented by (O) and observed Castle Hayne concentration means (n=4) are represented by (Δ).



Raleigh (March)--------------------------(April)--------------------------(May)----------------

Castle Hayne (May)-----------------------------(June)---------------------------(July)----------------

Figure 2.3. Daily average air temperatures during Preen (trifluralin) dissipation studies at Raleigh, NC and Castle Hayne, NC.

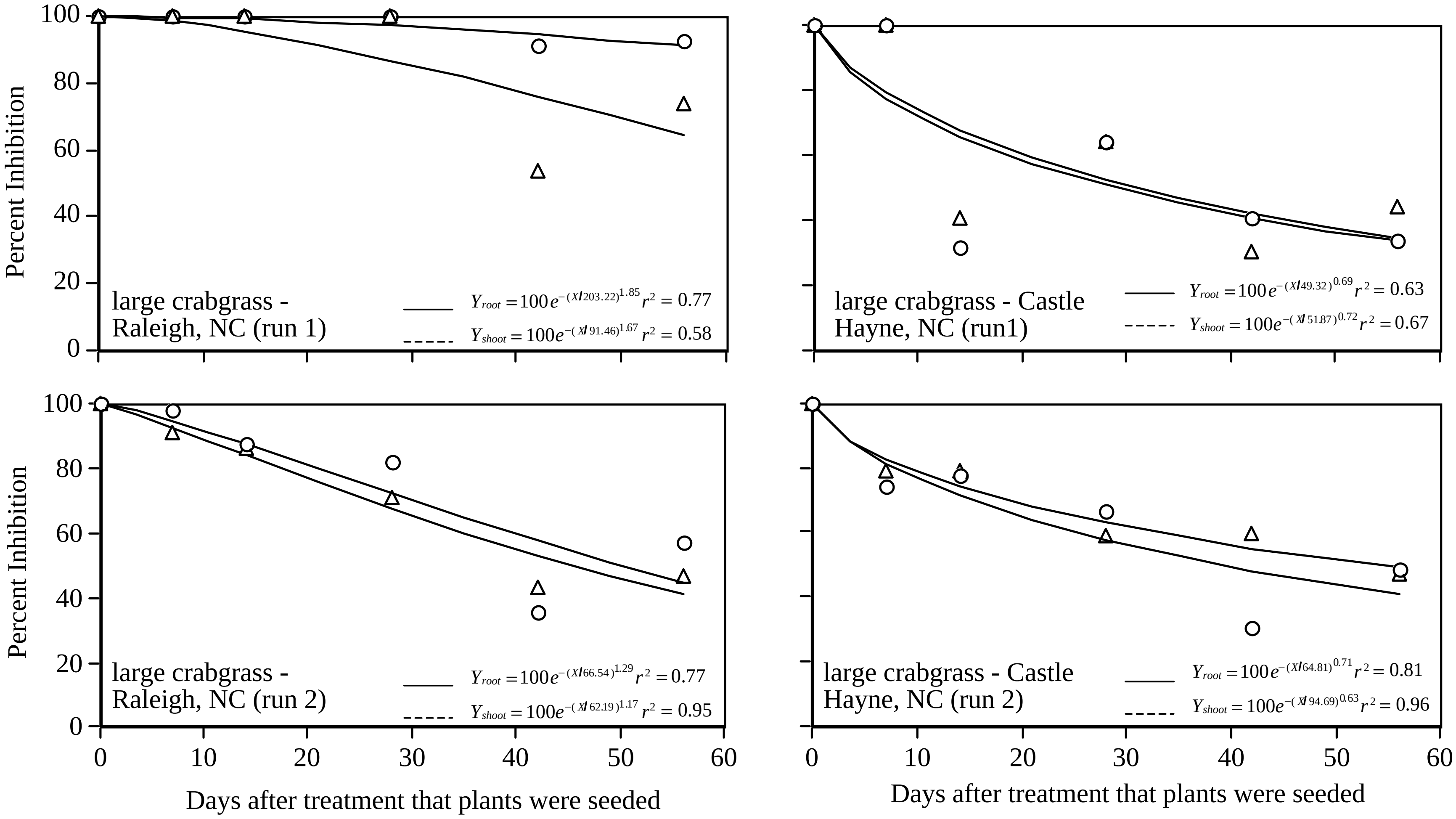


Figure 2.4. Inhibition (expressed as a percent of the non-treated) of root and shoot growth of large crabgrass by preemergence applications of Preen (trifluralin) over time. Response curves were fit to a Weibull model: $Y = A + e^{-(X/\sigma)^C}$ where A, C, and σ are estimated parameters and X is days after treatment that plants were seeded. Y_{root} is the predicted root inhibition curve (——) and Y_{shoot} is the predicted shoot inhibition curve (- - - -). Observed root means (n=4) are represented by (O) and shoot means (n=4) are represented by (Δ).

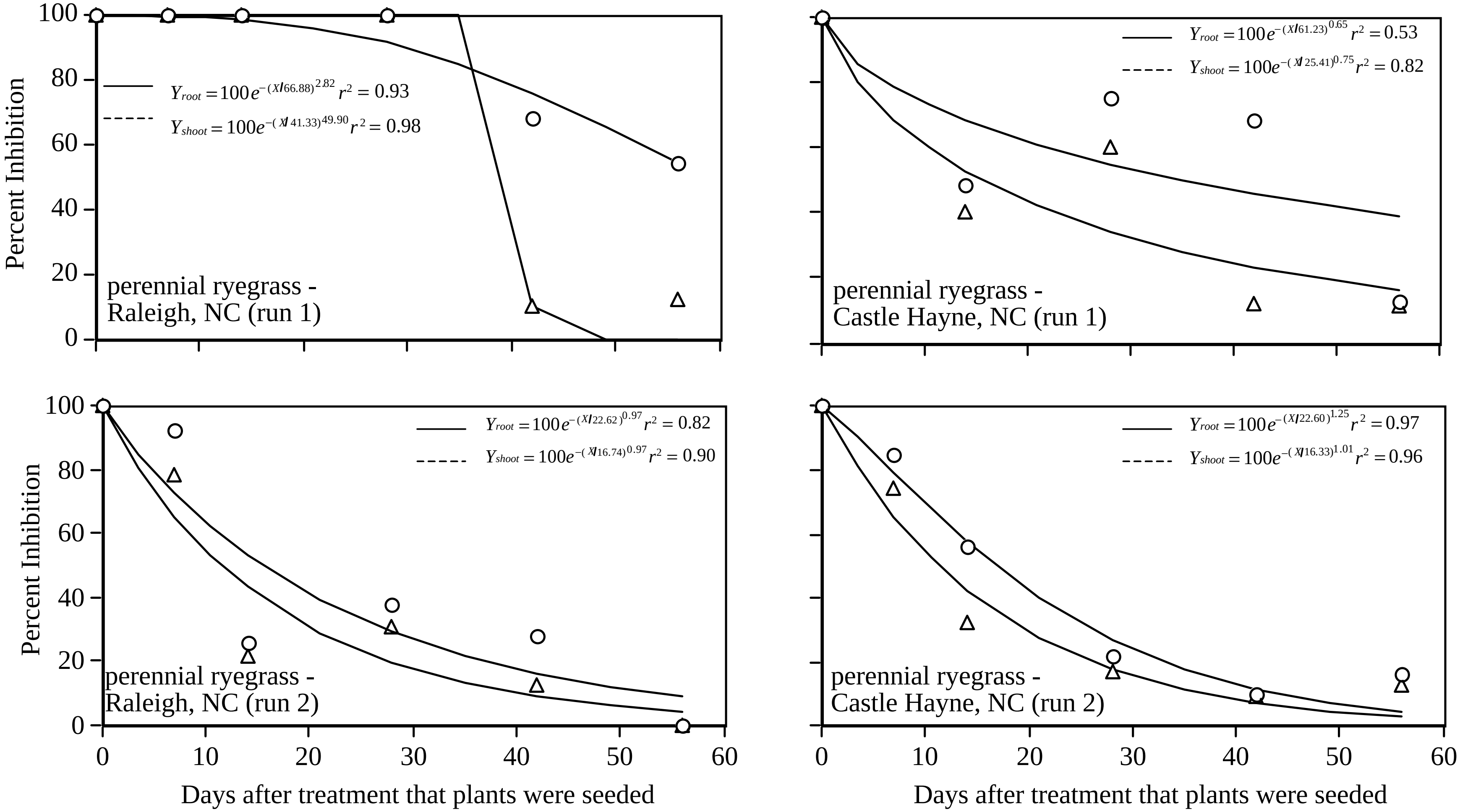


Figure 2.5. Inhibition (expressed as a percent of the non-treated) of root and shoot growth of perennial ryegrass by preemergence applications of Preen (trifluralin) over time. Response curves were fit to a Weibull model: $Y = A + e^{-(X/\sigma)^C}$ where A, C, and σ are estimated parameters and X is days after treatment that plants were seeded. Y_{root} is the predicted root inhibition curve (——) and Y_{shoot} is the predicted shoot inhibition curve (- - - -). Observed root means (n=4) are represented by (O) and shoot means (n=4) are represented by (Δ).

Discussion and Conclusions

Weed management in container nursery crop production is expensive and labor intensive. Because few postemergence herbicides are available for safe, broad-spectrum weed control, multiple preemergence applications supplemented with hand weeding are relied upon for weed management, particularly during the summer growing season. Container substrates may include sand, but all other components are generally lightweight soilless organic matter such as pine bark, peat moss, and wood shavings. In the southeastern U.S., the most common nursery substrate is a pine bark and sand mix. Herbicide interactions and dissipation in soils have been well documented. Additionally, herbicide runoff and leaching studies have been document in nursery soilless substrates. However, limited information is available regarding herbicide longevity in nursery substrates.

Currently, growers wait until weed emergence to determine when herbicides have dissipated to ineffective levels, whether due to leaching, volatilization or microbial degradation. Before another preemergence herbicide application is made, all emerged weeds must be removed by hand, an expensive and laborious task. In an effort to better predict when herbicide concentrations have dissipated to ineffective levels, aqueous concentration response experiments, dose-response experiments and dissipation experiments were conducted. All of these data can be used to develop a predictive assay or model which growers can use to accurately and rapidly predict when herbicide concentrations have reached ineffective levels, and consequently know when to reapply herbicides. This would improve the current method of waiting for weed emergence.

Aqueous concentration response experiments were conducted in glass petri dishes to evaluate several common ornamental herbicides including Gallery 75DF (isoxaben), Surflan

4AS (oryzalin) and Treflan 4EC (trifluralin). These herbicides were evaluated over a range of broadleaf and grass weed species including eclipta (*Eclipta prostrata*), hairy bittercress (*Cardamine hirsuta*), large crabgrass (*Digitaria sanguinalis*) and spotted spurge (*Euphorbia maculata*). Additionally, potential bioassay species, oats (*Avena sativa* 'Rodgers') and lettuce (*Lactuca sativa* 'Black-seeded Simpson'), were included. Perennial ryegrass (*Lolium perenne*) was also included in the Treflan experiments as another sensitive grass species. The herbicide concentrations evaluated ranged from 0 to 5 μg ai/mL. Root and shoot growth were measured and expressed as a percent of the non-treated. Concentrations providing 80% inhibition (I_{80}) were determined by non-linear regression analysis. Gallery concentrations required for 80% inhibition were 1.3 and 0.4 for eclipta, 0.4 and 3.9 for hairy bittercress, 0.5 and 0.3 for spotted spurge, 1.5 and 0.3 for large crabgrass, and 1.6 and 0.1 μg ai/mL for lettuce shoot and root, respectively. Surflan I_{80} values were 9.8 and 0.4 for eclipta, 5.9 and 1.6 for hairy bittercress, 1.2 and 1.4 for spotted spurge, 1.2 and 0.1 for large crabgrass, and 17.4 and 0.6 μg ai/mL for lettuce shoot and root, respectively. Treflan I_{80} values were 73.8 and 3.4 for eclipta, 17.3 and 7.4 for hairy bittercress, 6.2 and 9.2 for spotted spurge, 1.1 and 0.5 on large crabgrass, 7.2 and 8.4 for lettuce, and 0.9 and 1.2 μg ai/mL for perennial ryegrass shoot and root, respectively. I_{80} values for oats were well beyond the concentration range tested and extrapolated values were not realistic for Gallery or Surflan. However, Treflan I_{80} values were 0.5 and 2.1 μg ai/mL for oats shoot and root, respectively. The relative response of these problem weeds to common nursery herbicides coincides with relative susceptibility in container nursery production and efficacy trials. Because of this correlation, these concentrations may be reliable predictors of herbicide ineffectiveness.

After concentration response experiments, research focused specifically on trifluralin (Treflan, Preen) and grass inhibition as a model system. Trifluralin is a dinitroaniline herbicide, which is a family of preemergence herbicides with excellent crop safety that is widely used in container nursery production for grass and small-seeded broadleaf control. Furthermore, trifluralin is a component of a common preemergence nursery pre-packaged product, Snapshot TG. Isoxaben is the other component, which is effective on a broader range of broadleaf weeds.

Treflan dose-response experiments were conducted in the greenhouse and outdoors to evaluate control of two grass species, large crabgrass and perennial ryegrass. Visual estimates of percent control and shoot fresh weight (expressed as a percent of the non-treated) were determined. By using non-linear regression analysis, 80% inhibition values were determined. Not surprisingly, it took lower rates of Treflan to control the species in the greenhouse than outdoors. Approximately 1.0 kg ai/ha (0.89 lb ai/A) was required for 80% control in the greenhouse 6 weeks after treatment (WAT). Outdoors, 3.0 kg ai/ha (2.68 lb ai/A) was required at the same time interval. However, 3 WAT, less than 2 kg ai/ha (1.79 lb ai/A) was required for equivalent control. These data show that current use-rates of Treflan are effective against susceptible species. Although Treflan alone is not always consistent on these species. Additionally, it shows that between 3 and 6 WAT, Treflan is dissipating rapidly since lower rates are required 3 WAT for similar control 6 WAT.

Trifluralin is a volatile compound with very low water solubility. This prevents it from leaching in container substrates making it available for plant uptake in the substrate surface for a period of time. The half-life of trifluralin has been well documented in many soil types and climatic regions. However, it has not been documented in soilless nursery substrates. Therefore, outdoor container experiments were conducted at two locations (Raleigh, NC and Castle Hayne, NC) throughout the growing season. Trifluralin dissipation was quantified over time using substrate extraction and gas chromatographic techniques, and data are expressed on a dry weight basis. Additionally, large crabgrass and perennial ryegrass growth were measured over the same period of time to correlate concentrations with weed inhibition. It was determined that trifluralin half-life values were less than 5 days in soilless nursery substrates, significantly less than most soils. These half-life values corresponded with those obtained in soils of tropical regions. Trifluralin dissipates more rapidly under high temperatures and high moisture regimes. In the southeastern U.S., nurseries are under intensive daily irrigation, up to 2.5 cm (1 in) per day, and exposed to high temperatures throughout the growing season. While trifluralin dissipated quickly at both locations, concentrations remained higher (less had dissipated) in the March to May experiment (Raleigh) than the May to July experiment (Castle Hayne). Temperature data confirmed that the temperatures at Castle Hayne were higher than those of Raleigh, especially during the first week of the experiment, the period of the most rapid dissipation.

Based on non-linear regression analysis, days to 20% and 50% growth of large crabgrass and perennial ryegrass were determined. This growth occurred sooner over time in the Castle Hayne experiment than in the Raleigh experiment, which corresponded well to the lower trifluralin concentrations at Castle Hayne. Although it appeared that temperatures dictated how soon and how much trifluralin dissipated, inhibitory concentrations for weed growth were quite consistent. For example, 20% large crabgrass root growth occurred when trifluralin concentrations were 12.5 and 15 μg/g for the Raleigh and Castle Hayne runs, respectively. For 50% large crabgrass root growth, concentrations were 4.1 and 10.3 μg/g.

Similarly, for 20% large crabgrass shoot growth, concentrations were 13.4 and 18.1 μg/g, and for 50% growth concentrations were 3.8 and 13.4 μg/g. For 20% perennial ryegrass root growth, trifluralin concentrations were 15.0 and 17.7 μg/g, and for 50% root growth concentrations were 3.4 and 14.7 μg/g in the Raleigh and Castle Hayne tests, respectively. For 20% perennial ryegrass shoot growth concentrations were 17.5 and 23.2 μg/g, and for 50% shoot growth concentrations were 7.0 and 17.3 μg/g. Based on this information, one option to improve herbicide performance might be to apply lower rates of trifluralin more frequently. This option may allow for the maintenance of adequate concentrations for weed control without the initial loss of trifluralin. Another way to utilize this information might be the development of slow-release herbicides. For such strategies or formulations, herbicide applicators or formulation release rates will need to target the maintenance of extractable trifluralin concentrations greater than 23 μg/g, the highest concentration where weeds were no longer controlled.

The amount quantified by gas chromatography accounted for all extractable trifluralin present in the sampling region. However, not all trifluralin present in the germination zone is available for plant uptake. Therefore, the aqueous concentration experiments may account for actual trifluralin in aqueous solution inhibitory to plant growth. If an assay system is developed, it will be necessary to differentiate between these two types of inhibitory concentrations, those extractable and those available for plant uptake in the germination zone. Based on 20% and 50% growth of both large crabgrass and perennial ryegrass root and shoot, extractable inhibitory concentrations ranged from 3.4 to 23.2 μg/g. In petri dish culture, concentration ranges for 80% inhibition for sensitive species ranged from 0.1 to 3.9 μg ai/mL.

Overall, a range of concentrations is known, both extractable and those available for plant uptake, where herbicides are losing effectiveness on troublesome nursery weeds. We also know that dissipation of trifluralin in soilless substrates occurs quicker than is currently thought and is similar to soils of tropical regions. These data could have major implications to weed management, herbicide efficiency and the need for hand weeding in container nurseries. This further highlights the need for the development of an assay or predictive model that can accurately and rapidly determine herbicide dissipation.

Finally, further research needs to be conducted in container nursery systems with regards to herbicide dissipation. Other important nursery herbicides such as oryzalin, pendimethalin, oxyfluorfen and isoxaben need to be evaluated to determine if they have similar dissipation patterns to those of trifluralin. When all these data are considered, weed management in container nursery production might need to be altered in order to properly time preemergence herbicide applications and avoid unnecessary hand weeding.

Appendix

Table A.1. Hairy bittercress (*Cardamine hirsuta)* response to a Treflan (trifluralin) dose-response in a preliminary greenhouse experiment.

Treflan rate (kg ai/ha)	Visual control (%)	Fresh weight (g)
0.0	0	3.3
0.07	0	8.6
0.14	5	6.9
0.28	10	5.2
0.56	0	9.2
1.12	5	7.8
2.24	18	6.1
$P_{0.05}$	NS	NS

Table A.2. Eclipta (*Eclipta prostrata)* response to a Treflan (trifluralin) dose-response in a preliminary greenhouse experiment.

Treflan rate (kg ai/ha)	Visual control (%)	Fresh weight (g)
0.0	0	3.1
0.07	0	4.6
0.14	15	3.6
0.28	30	1.8
0.56	20	2.0
1.12	43	3.2
2.24	58	1.4
$P_{0.05}$	0.0423	NS

Table A.3. Lettuce (*Lactuca sativa* 'Black-seeded Simpson') response to a Treflan (trifluralin) dose-response in the greenhouse preliminary experiment.

Treflan rate (kg ai/ha)	Visual control (%)	Fresh weight (g)
0.0	0	24.3
0.07	0	25.3
0.14	0	23.9
0.28	0	20.9
0.56	0	23.9
1.12	5	20.6
2.24	15	21.6
$P_{0.05}$	0.0045	NS

Table A.4. Oats (*Avena sativa* 'Rodgers') response to a Treflan (trifluralin) dose-response in a preliminary greenhouse experiment.

Treflan rate (kg ai/ha)	Visual control (%)	Fresh weight (g)
0.0	0	11.0
0.07	0	11.7
0.14	0	11.4
0.28	0	10.4
0.56	0	10.3
1.12	0	10.6
2.24	5	8.0
$P_{0.05}$	NS	NS

Table A.5. Spotted spurge (*Euphorbia maculata)* response to a Treflan (trifluralin) dose-response in a preliminary greenhouse experiment.

Treflan rate (kg ai/ha)	Visual control (%)	Fresh weight (g)
0.0	0	0.9
0.07	8	1.2
0.14	35	0.5
0.28	30	0.8
0.56	18	0.4
1.12	73	0.4
2.24	90	0.1
$P_{0.05}$	0.0029	NS

Table A.6. Aqueous concentrations of Gallery (isoxaben), Surflan (oryzalin) and Treflan (trifluralin) required for 80% inhibition (I_{80}) of root and shoot growth of oats (*Avena sativa* ‘Rodgers’) as determined by petri dish assays. I_{80} values (n=8) determined from regression curves (Appendix figure A.1).

	Herbicide		
Oats	Gallery	Surflan	Treflan
	µg ai/mL		
shoot	220163.4*	106.0*	0.5
root	4275.0*	15.0*	2.1

* extrapolated values

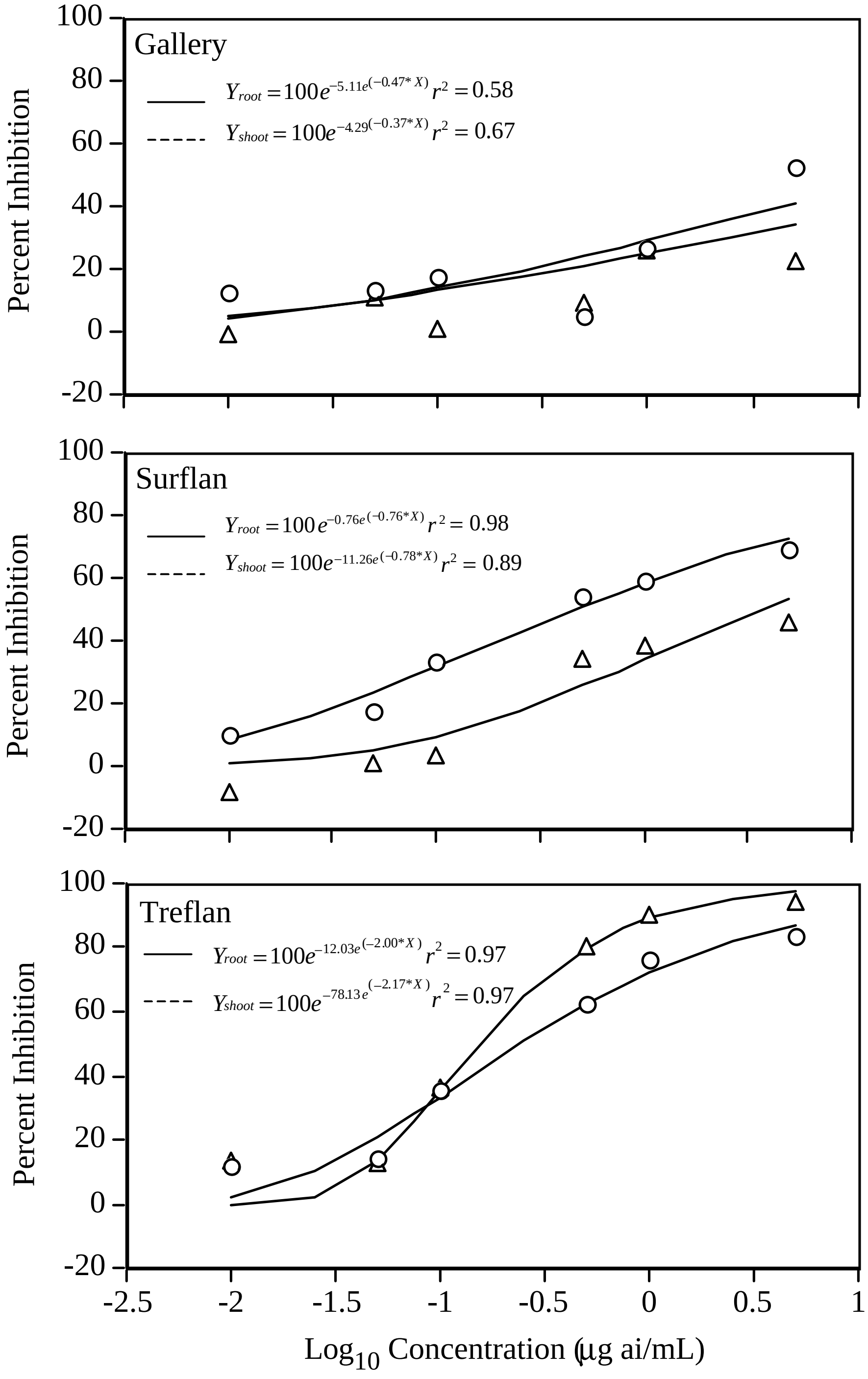


Figure A.1. Inhibition of root and shoot growth (expressed as a percent of the non-treated) of oats by aqueous concentrations of Gallery (isoxaben), Surflan (oryzalin) and Treflan (trifluralin). Response curves were fit to a Gompertz model: $Y = 100e^{-Be^{(-K*X)}}$ where K and B are estimated parameters and X is (Log$_{10}$ + 3) of the herbicide concentration (µg ai/mL) (Table 1.1). Y_{root} is the predicted root curve (——) and Y_{shoot} is the predicted shoot curve (- - - -). Observed root inhibition means (n=8) are represented by (O) and shoot inhibition means (n=8) are represented by (Δ).