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Recovery of Imidacloprid from Leachate and Soil

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Abstract. Greenhouse experiments simulated field treatments with Premise® 75 WP imidacloprid insecticide at the highest recommended labeled rate (0.10% AI) for prevention and control of subterranean termites around and within structures. Persistence of imidacloprid was examined in treated sandy loam soil with and without vegetation. Samples from soil substrates and leachates collected 1, 3, 6, 9, and 12 months after treatment during a 1-year post-treatment period were analyzed by high-performance liquid chromatography. The mean concentrations of imidacloprid in the treated soil and leachate immediately after application were 842.6 ± 9.2 µg per gram and 941.5 µl per liter, respectively. Recovery of imidacloprid utilizing high-performance liquid chromatography was 84.2 ± 9.2 and 94.5 ± 10.6%, respectively. No imidacloprid was found in soil or leachate 6 months after treatment. The results indicated that imidacloprid was soluble and leached from the treated soil.

Introduction

Subterranean termites (Rhinotermitidae) are a major threat to wooden components of structures. In Texas, prevention, control, and remediation of damage by subterranean termites cost approximately $2 billion per year. Liquid termiticides are the primary pre- and post-construction approaches to termite control. Persistence, bio-availability, and effectiveness of termiticides in soil types and environmental conditions have been researched in Texas (Gold et al. 1993, 1994, 1996a,b; Kuriachan and Gold 1998; Keefer et al. 2010, 2011). There are concerns that termiticides do not adequately bind to soil matrices, and thus might pose environmental challenges such as leaching or accelerated dissipation that could lead to loss and off-target movement of active ingredient from the treated zone (Smith and Rust 1992, Gold et al. 1996a). Additionally, this would reduce the overall effectiveness of a termiticidal treatment. Product biotic or abiotic degradation in, dissipation from, or translocation through the soil at fast rates would result in a lesser degree of effectiveness than more stable termiticides to control subterranean termites through time desired by homeowners, pest management professionals, and termiticide manufacturers.

Insecticide effectiveness is influenced by factors related to soil composition, such as mineral composition, soil temperature, soil type, pH, insecticide type, moisture, organic matter, microbial activity, and weather (Harris 1972, Forschler and

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Townsend 1996, Kamble and Saran 2005). The measurements of pesticide residue in soil might not adequately predict long-term insecticidal efficacy, because they do not consider all the complex biotic and abiotic interactions that can have deleterious effects on the termiticides. Abiotic and biotic reactions (hydrolysis, photolysis, and oxidation) of insecticides designated for termite control have been documented (Austin 1999, Baskaran et al. 1999, Kamble and Saran 2005, Shuai et al. 2012). Other factors affecting efficacy of a termiticide are susceptibility and behavioral reaction of the termites to the chemical. The tolerance differences among species, life stages, and castes, the mode of application, and the formulation of the compound could affect the persistence or continued effectiveness of a chemical over time (Harris 1972).

Imidacloprid, first synthesized in 1985 (Sur and Stork 2003), was introduced as the termiticide Premise® 75 in 1996 by Bayer Environmental Sciences (Gahloff and Koehler 2001). This formulation was marketed as a non-repellent (Osbrink and Lax 2003, Osbrink et al. 2005, Parman and Vargo 2010), slow-acting insecticide (Matsuda et al. 2001, Osbrink et al. 2005), and as an inhibitor of feeding (Ramakrishnan et al. 2000) and tunneling (Kuriachan and Gold 1998). Imidacloprid was reported to be transferred in lethal doses between and among termite workers (Thorne and Breisch 2001, Shelton and Grace 2003, Tomalski and Vargo 2004, Parman and Vargo 2010). In addition, imidacloprid has systemic properties (Gonzalez-Prades et al. 1999) because of solubility of the active ingredient in water which results in movement of the chemical from the soil into plant vascular tissues (Carretero et al. 2003, Peterson 2007). These systemic properties have allowed imidacloprid to be used to successfully control important agricultural pests such as aphididae, cicadellidae, aleyrodidae, chrysomelidae, and pseudococcidae (Gill et al. 1999, Cowles et al. 2005, Rogers et al. 2007). The objectives of this study were to determine longevity, mobility, and dissipation of imidacloprid in simulated field studies using sandy loam soil (from College Station, TX) and plants commonly found in urban environments.

Materials and Methods

Soil Preparation. Nineteen-liter buckets (Letica Corporation, Rochester, MI) had five 2.54-cm-diameter holes drilled in a circular pattern in the bottom for collection of leachate. Fiberglass silver-gray window screen (Phifer Incorporated, Tuscaloosa, AL) was cut 24 cm in diameter in a circular pattern and attached with liquid adhesive (Liquid Nails, Strongsville, OH) over the interior bottom of the bucket. The adhesive was allowed to dry for 24 hours, after which 7.64 cm (approximately 7.14 kg) of washed sand (Premium Play Sand, Quikrete® International, Inc., Atlanta, GA) was added to the bucket.

To determine the amount of soil to be treated and added to each experimental unit (individual bucket), a simulated trench was formed using southern yellow pine lumber. The form was 3.05 m long by 15.24 cm wide and 15.24 cm deep, and simulated a soil termiticide treatment trench next to a structure, and would accommodate recommendations of the manufacturer's application rate of 15 liters of finished solution of termiticide per 3.05 linear meters to a depth of 0.30 m. The soil from the College Station, TX area was a commercially available sandy loam with 5.9 pH, 72% sand, 18% silt, 10% clay, and 1.0% organic matter. To fill the form required 84.6 kg of soil, and this weight was used when calculating the amount of Premise® 75 WP needed to meet the labeled concentration for a soil

application at 14.8 liters (0.1% imidacloprid) per 3.1 m. The result was 1,000 µg of imidacloprid per kilogram of soil.

A total of 84.6 kg of soil was added to the drum of a cement mixer (Model 59020CF, Gilco Incorporated, Grafton, WI). Premise® WP 75 termiticide was added at the greatest recommended labeled application rate of 0.10% AI to 3.6 liters of water. The termiticide was slowly added to the soil by using a course jet fan spray from a hand-held pump sprayer (B&G Equipment, Jackson, GA). The sandy loam soil was mixed for 20 minutes at a constant rate of 20 revolutions per minute. After thorough mixing, 20.32 cm (depth) (weighing 21.05 kg) of treated soil was placed on top of the sand in each of the 19-liter buckets. In each bucket, one of the following species of plant was seeded or transplanted: St. Augustine grass, *Stenotaphrum secundatum* (Walter) Kuntze; Bermuda grass, *Cynodon dactylon* (L.); Mexican heather, *Cuphea hyssopifolia* Kunth; and red-tip photinia, *Photina x fraseri* Dress. Bermuda grass was grown from seed (Pennington Seed, Inc., Madison, GA), and the other three species were transplanted as mature vegetation. After the Mexican heather and red-tip photinia were planted, a thin layer of sphagnum peat moss (Miracle Gro, Marysville, OH) was applied to promote growth. All of the replications were watered at regular intervals to promote healthy plant growth. During the summer, each replication received 1 liter of water two or three times a week. In the fall, spring, and winter, water was reduced to 1 liter once or twice a week. There were three replications of each plant species, for a total of 12 buckets. The checks were: 1) soil without termiticides or plants (three); 2) soil with termiticide and no plants, used for no plant data and horizon data (three); and 3) soil with each of the four plant species, but with no termiticide (12), for a total of 18 check buckets. Thirty test units were used. The study was done during one calendar year and maintained in a greenhouse at College Station, TX.

Soil Extraction and Sampling. Immediately after application of termiticide and establishment of experimental units (Time Zero), three samples were taken from the imidacloprid-treated soil and analyzed to ensure the target concentration of 1,000 µg per gram. A stainless steel T-bar soil probe with a 25 x 2.5 cm plastic sleeve inserted into the probe to capture the soil core was used to collect samples from the buckets at 1, 3, 6, 9, and 12 months post-treatment. After the soil sample was taken, the sleeve was labeled, and the top was covered with a red cap and the bottom with a blue cap. All soil samples were kept at -5°C in a freezer. All sampling holes made with the soil probe in the buckets were filled with Quikrete Premium Play Sand (white) immediately after sampling to keep the structure of the soil in place and avoid sampling sequentially from the same location within respective replications, because sampling was done randomly.

To prepare for analysis by high-performance liquid chromatography, the soil samples were separated into top, middle, and bottom sections. The top cap (red) of the soil probe sleeve was removed, and approximately 15 g (8 cm) of soil (top) was placed in a 5.5-cm weigh-boat, labeled, and allowed to air dry overnight at 25 ± 2°C. The next 15 g (8 cm) of soil was removed from the sleeve and labeled as the middle. The last 15 g (8 cm) of soil was pushed from the sleeve and labeled as the bottom. After drying, 5 g of soil from each of the sections was removed from each weigh-boat, placed into a separate 40-ml vial, and 15 ml of acetonitrile was added. The contents of the vial were agitated by hand for 20 seconds, allowed to settle for 24 hours, after which 1 ml of supernatant was taken with a micropipette and put into a 1.5-ml scintillation vial (National Scientific Company, Rockwood, TN). The subsamples were kept at -5°C in a freezer until analyzed.

Leachate Sampling. Leachate (1 liter) was sampled 0, 1, 3, 6, 9, and 12 months post-treatment. The plant and soil were irrigated with 2 liters of water sufficient to fill a 1-liter Nalgene bottle (Rochester, NY) with leachate during each sampling period; however, all replications were watered throughout the duration of the study to ensure continuous plant growth. Samples were taken by placing a funnel inserted into the 1-liter Nalgene bottle under the buckets suspended by two hollow-block bricks (Fig. 1). A vacuum pump (Cole Parmer L-79200-00, 115 v, 60 HZ) was used to prepare 1-liter leachate samples. A piece of 0.5-m-long, 0.31-cm internal diameter x 0.16-cm-thick wall Tygon® tubing was attached to the vacuum pump and the other end attached to a Resprep™ 12-port Solid Phase Extraction Manifold. Pressure (-103.4 kPa) on the vacuum pump was set so activation of the cartridge occurred within 10 minutes. A Resprep™ 60 ml C18 cartridge (Restek, Bellefonte, PA) had a mixture of 50 ml of 80% acetonitrile/20% high-performance liquid chromatography grade water pulled through it by the vacuum pump to activate the column beads within the C18 cartridge. Then, 150 ml of high-performance liquid chromatography grade water was pulled through to wash the solvent solution from the C18 column matrix (beads), after which 100 ml of leachate was passed through the column and the imidacloprid attached to the activated beads. The imidaclopid was released from the beads when 100 ml of 80% acetonitrile/20% high-performance liquid chromatography grade water solvent was passed through the column and collected in a 120-ml Nalgene bottle. A 1.0-ml subsample of elute was pipetted and placed into a 1.5-ml scintillation vial and stored at -5°C until analysis by high-performance liquid chromatography. The methodology is described by Placke and Webber (1993) and Baskaran et al. (1997, 1999).

Fig. 1. Leachate was collected by placing a funnel inserted into a 1-liter Nalgene bottle under a bucket suspended by two hollow-block bricks.

High-Performance Liquid Chromatography. Analysis by high-performance liquid chromatography of the termiticide in soil and leachate samples was on a 1200 series Agilent HPLC system (Waldbronn, Germany) equipped with an ultra violet-visible photodiode array detector that registered the data as total milli-absorbance units (maU) arrayed under a chromatographic curve, the area of which was correlated to the concentration (µg per gram or µl per liter) of imidacloprid in each of the samples based on a standard dilution curve. Standard curves were prepared with technical-grade imidacloprid at 99.5% purity purchased from Chem Service (West Chester, PA) to make serial dilutions. The only pesticide analysis was for imidacloprid; no metabolites were assessed. To make the stock solution for each serial dilution, 0.10 g of technical-grade imidacloprid was mixed in 100 ml of acetonitrile to make a 1000 µl per liter solution. From the stock solution, a 10-fold dilution series was made of 0.1, 1.0, 10, 100, and 1000 µl per liter of imidacloprid. To help quantify the serial dilutions, a best fit line was generated and used to estimate the concentration of imidacloprid in samples after they were analyzed by high-performance liquid chromatography. The concentrations were correlated to an intersection point of the best fit line (Fig. 2) wherein the mean number of maU reported was proportionately correlated on the curve, by the integrator. This method was used to quantify the amount of termiticide concentrations in the soil and leachate samples throughout the study.

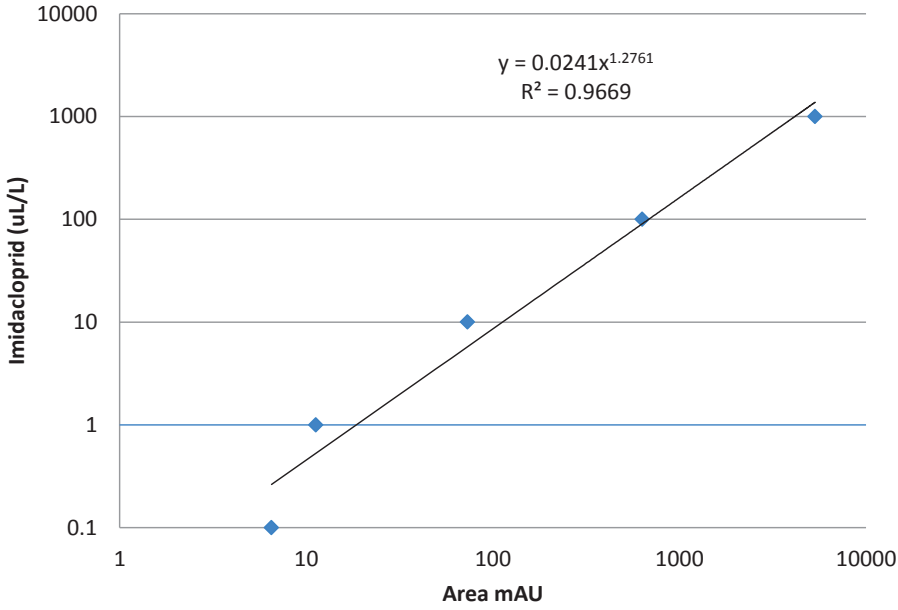

Fig. 2. Detector linearity of Agilent (model 1200 series) high-performance liquid chromatography equipped with an ultraviolet diode array detector; λ = 270, eluted by a Zorbax Eclipse XDB-C18 analytical 4.6 x 150 mm 5-micron column; limit of quantification was 0.1µl per liter.

A one-way analysis of variance (ANOVA) (SPSS 2007) was used to compare the concentration of active ingredient recovered from soils associated with the different plant species and all post-treatment observations. Means were separated using Tukey's honest significant difference test (p = 0.05).

Results

A serial dilution of known concentration of imidacloprid was prepared and analyzed to calibrate the high-performance liquid chromatography instrument and ensure detector linearity. The mean retention time for the imidacloprid dilutions across all concentrations and sampling periods was 4.25 ± 0.05 minutes. The mean percentage milli-absorbance unit (mAU) followed by the standard deviation across concentrations in the serial dilutions from low to high of imidacloprid were 6.51 ± 7.47(0.1 µl per liter), 11.26 ± 3.66 (1.0 µl per liter), 73.19 ± 13.57 (10.0 µl per liter), 631.63 ± 97.76 (100.0 µl per liter), and 5,340.34 ± 626.04 (1,000.0 µl per liter). In this case, mAU was defined as a logarithmic unit to measure optical density which had a direct relationship to the area under the peak in the chromatogram. The mean correlation (R^2) value for the serial dilutions was 0.9669. The values used to calculate the means were used to determine the amount of imidacloprid in the leachate and soil samples.

The mean recovery of imidacloprid in leachate at Time Zero was 941.5 ± 10.6 µl per liter (treated soil only, no plants). The mean amount of imidacloprid recovered 1 month after treatment from leachate associated with plants ranged from 302-443 µl per liter (Table 1). The mean amount of imidacloprid in replications without plants was 435.2 ± 96.9 µl per liter. At 3 months after treatment, no imidacloprid was detected in the soil samples from the buckets with Mexican heather, but imidacloprid was detected in leachate associated with the other three species of plants and with replications without plants (Table 2). The mean amount of imidacloprid recovered from the leachate at 3 months after treatment across all plant species ranged from 0.0-23.3 µl per liter, and the mean concentration from the replications without plants was 66.1 ± 36.0 µl per liter (Table 1). At the 6-, 9-, and 12-month sampling periods, no imidacloprid was detected by high-performance liquid chromatography in any leachate sample, with or without plants.

The mean recovery concentration of imidacloprid in soil at Time Zero was 842.6 ± 9.2 µg per gram (soil only, no plants). The mean recovery concentration of

Table 1. Mean Concentration (µl per liter) Detected by High-Performance Liquid Chromatography of Imidacloprid 0.10% AI in Leachate in Association with Various Plants through Time

MPT[a]	Red tip Photinia	St. Augustine grass	Bermuda grass	Mexican heather	No plant
1	301.90±140.60a	442.65±83.33a	387.21±85.22a	409.65±108.38a	435.17±96.91a
3	23.31±31.43b	3.67±5.89b	8.09±12.04b	0.00±0.00b	66.12±36.02b
6	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00b	0.00±0.00c
9	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00b	0.00±0.00c
12	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00b	0.00±0.00c

Means followed by the same letter in a column are not significantly different (p = 0.05) per Tukey's HSD (honest significant difference).
[a]MPT = months post-treatment

Table 2. Mean Concentration (µg/g) by High-Performance Liquid Chromatography of Imidacloprid 0.10% AI through Time in Soil (all Horizons) in Association with Plants

MPT[a]	Red tip Photinia	St. Augustine grass	Bermuda grass	Mexican heather	No plant
1	20.98±8.42a	26.65±19.53a	20.09±8.54a	14.83±12.82a	3.65±1.12a
3	0.59±1.13b	0.78±1.29b	0.92±1.00b	0.17±0.11b	0.00±0.00b
6	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00b
9	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00b
12	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00b

Means followed by the same letter in a column are not significantly different (p = 0.05) per Tukey's HSD (honest significant difference).
[a]MPT = months post-treatment

imidacloprid ranged from 14.83-26.65 µg per gram 1 month after treatment of soil with plants. There were significant differences in recovery of imidacloprid between some plant and no-plant replications 1 month after treatment (Table 2). The mean amount of imidacloprid at 3 months post-treatment of soil with plants was ≤1.0 µg per gram and from replications with no plants was 0.0. At 6, 9, and 12 months, no imidacloprid was detected in any soil sample via high-performance liquid chromatography.

The concentrations of imidacloprid in soils separated by horizon were 17.04 ±12.98 (top), 13.90 ± 9.72 (middle), and 22.43 ± 20.09 µg per gram (bottom) (Table 3). Results for soils separated by horizon at 3 months post-treatment are in Table 3. No imidacloprid was detected in any horizon by high-performance liquid chromatography in soil samples 6, 9, and 12 months after treatment.

Table 3. Mean Concentration (µg/g) of Imidacloprid 0.10% AI Detected in Soil Horizons via High-Performance Liquid Chromatography through Time

MPT[a]	Soil horizon		
	Top	Middle	Bottom
1	17.04 ± 12.98 a	13.90 ± 9.72 a	22.43 ± 20.09 a
3	0.58 ± 1.76 b	0.31 ± 1.40 b	0.53 ± 1.76 b
6	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c
9	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c
12	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c

Means followed by the same letter in a column are not significantly different (p = 0.05) per Tukey's HSD (Honest Significant Difference).
[a]MPT = months post-treatment.

Discussion

The mean yield of imidacloprid at Time Zero was 842.6 ± 9.2 in soil and 941.5 µl per liter in leachate. Separation and detection of imidacloprid in crop-related studies has been successful with high-performance liquid chromatography without derivatization (Ishii et al. 1994, Baskaran et al. 1997). A reversed-phase

high-performance liquid chromatography method following extraction with acetonitrile/water (1/4, v/v) and cleanup using a silica gel column was developed for detecting imidacloprid in water and soil samples and is well regarded. The limits of detection of the high-performance liquid chromatography method were between 0.005 and 0.02 mg per kilogram of imidacloprid (Ishii et al. 1994), which is consistent with the methods in this study. The results of this study agree with those of Baskaran et al. (1997) who used high-performance liquid chromatography to recover 82-88% of imidacloprid in soil and 82-95% in leachate.

The environmental fate of imidacloprid has been investigated. The half-life of imidacloprid in soil is 48-190 days, depending on ground cover, organic material (Scholz and Spiteller 1992, Rouchard et al. 1994). Miles Inc. (1993) reported the half-life of imidacloprid in soil ranged from 27-229 days. The water solubility of 0.51 g per liter and organic carbon partition coefficient (K_{oc}) value of 221 indicated imidacloprid has a low tendency to adsorb to soil particles which reduced the probability the compound could provide long-term protection against subterranean termites in structures, relative to longer-lasting compounds (Bacey 2000). The water solubility and soil organic carbon-water partitioning coefficient values of imidacloprid affect longevity and movement of the chemical in soil. These factors might influence adsorption to soil and mobility of imidacloprid in the environment. A low K_{oc} value coupled with high water solubility suggests imidacloprid could leach and move through soil and out of the target zone, thereby potentially having a reduced effect on target organisms. The results of our research support this, as indicated by the amounts of imidacloprid recovered in leachate and soil samples (Tables 1, 2). At 3 months, less imidacloprid was recovered from the leachate. The soil horizon data also showed imidacloprid was mobile in the environment, because no imidacloprid was recovered 3 months post-treatment (Table 3). The mobility of imidacloprid in soil was noted by Gupta et al. (2002). Less imidacloprid was recovered from soil at 3 months, which was the same trend as with the leachate and similar to results by Peterson (2007). Scholz and Spiteller (1992) found imidacloprid degraded more rapidly in the presence of vegetation as opposed to no ground cover, with estimated half-lives of 48 and 190 days, respectively. Less imidacloprid was recovered from leachate associated with plants, except St. Augustine grass, than from soil without plants (Table 1). This was generally in contrast to the recovery rate of imidacloprid from soil samples. The amount of imidacloprid in soil samples decreased at each time interval in the no-plant replications, except at 3 months post-treatment in Mexican heather and St. Augustine grass (Table 2). This suggested imidacloprid leached through the soil with watering. Imidacloprid has the potential to leach in runoff water, but field studies by Rouchard et al. (1994) and Miles Inc. (1993) showed the compound did not reach ground water. In contrast, studies in 1997 and 1998 by Bayer Corporation determined imidacloprid was capable of leaching into groundwater 5.5 meters below the surface. The concentration of imidacloprid detected was <0.01 to 1.0 ppb (Bacey 2000). It is our opinion that the subsoil was influential in exacerbating the loss of imidacloprid from the treatment zones, given ample watering required to maintain healthy plant growth during the study. Additionally, had more time been allowed before the first wash of insecticide, adsorbance might have been greater because adsorbance to soil is often greater with time (Kamble and Saran 2005).

No imidacloprid was detected after 3 months in either the leachate or soil samples (Tables 1, 2, 3). If imidacloprid is not detectable, it is unlikely the

compound offers continued long-term protection to structures when applied as a termiticide. And even if transformation to other metabolites occurred, there is little expectation known or published on effects to termites from dissipation metabolites of imidacloprid (Tomalski et al. 2010). Imidacloprid forms secondary metabolites (Bacey 2000) that have unknown effect on subterranean termites, but these were not assessed. Breakdown (hydrolysis) of imidacloprid in water results in the possibility of several other compounds that could negatively affect subterranean termites. This needs to be further investigated, because the incoordination of behaviors from eusocial insects exposed to sublethal concentrations of active ingredients has become a foci of research in the past decade, especially because it relates to foraging by honey bees, *Apis mellifera* (Schneider et al. 2012).

A key element in this study was the environment. All plants were maintained in a greenhouse where temperatures were warmer than outside during the summer. The greenhouse also had sunlight available to the plants during all daylight hours. The elevated temperatures and sunlight availability led to copiously watering the plants in the summer and spring to keep the plants healthy. All plants received 1 liter of water two or three times a week during the summer and 1 liter of water one or two times a week during the spring, thus possibly causing more leaching and chemical degradation than might occur under typical field conditions.

Longevity, translocation, and adsorption of active ingredients vary with environmental conditions. The results of this research indicated that imidacloprid did leach based on the concentration of active ingredient recovered through time in leachate. There were significant differences between the concentration of imidacloprid in the soil profile through time, which indicated movement of the active ingredients through soil and out of the target zone. There were also significant differences (p = 0.05) between concentrations of active ingredient in test units containing plants through time, thus indicating the active ingredient was mobile, and systemic uptake by plants was likely a contributing factor. Composite soils with more clay and/or less sand might have more favorable dissipation (for prolonged occurrence of imidacloprid) in soil. Without doubt, this phenomenon is influential in lethal exposures, where soil type and composition influence intoxication, uptake, and mortality to termites by imidacloprid (Austin 1999).

Because soil conditions adjacent to structures where termiticide is applied accelerated dissipation and biological transport (by plants), both might factor in persistence of imidacloprid-treated soils (Scholz and Spiteller 1992, Rouchard et al. 1994, Sarkar et al. 2001, Richman et al. 2006). Adsorption is directly influenced by soil organic matter acting as a sink whereby gradual availability of a termiticide is diminished by time. Richman et al. (2006) found inverse relationship between soil pH and mortality in which increased pH diminished residual activity of termitcides.

Imidacloprid is commonly used to control sucking insect pests of cotton (*Gossypium hirsutum* L.), sugarcane (*Saccharum offinarum* L.), rice (*Oryza sativa* L.), apples (*Malus domestica* Borkh.), and citrus (rutaceae) (Gupta et al. 2002). Because of its mode of action, it is effective against many pests resistant to carbamates, organophosphates, and pyrethroids (Oliveira et al. 2000). Benefits of imidacloprid include low mammalian toxicity and little to no negative effect on beneficial soil microbes. Another benefit of imidacloprid is that it is a slow-acting, non-repellent termiticide (Matsuda et al. 2001, Thorne and Breisch 2001) which allows long-term suppression of termite populations (Osbrink et al. 2005). In urban settings, imidacloprid could be formulated into a slow-release compound (Gupta et al. 2002) or mixed with a surfactant to intensify longevity of control (Camazano et al.

1995) to structures infested with subterranean termites. These benefits of imidacloprid make it a good option for control of many different pests in agricultural and urban environments.

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