EVALUATION of the LOUISIANA STATE PROGRAM to TREAT TREES INFESTED with FORMOSAN SUBTERRANEAN TERMITES (ISOPTERA: RHINOTERMITIDAE) in LOUISIANA

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Abstract The Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), is currently considered the most destructive insect in Louisiana. It attacks living trees eating the centers and constructing a carton nest within. Infested trees can serve as reservoirs for termites to infest structures. In an effort to reduce termite densities, public trees in the Greater New Orleans and Greater Lake Charles area were drilled by licensed pest management professionals and injected with insecticide foam. Evaluation on these treatments was carried out by the Louisiana State University (LSU) Agricultural Center on 168 heavily termite-infested trees. Evaluation trees were selected and inspected by LSU Agricultural Center personnel for termites before treatment. Treatments included fipronil (Termidor®), imidacloprid (Premise®), and control trees (treated with water). Trees were inspected for termites 1, 6, 12, and 18 months after treatment. Insecticide treatments significantly reduced the percentage of trees infested with Formosan and native subterranean termites compared to pretreatment percentages (100 %). The percentage of trees infested with Formosan subterranean termites observed in water treatments was not significantly different after treatment compared to pretreatment percentages (100 %). The lowest percentage of trees infested with Formosan subterranean termites at 18 months after treatment was observed in fipronil treatments. The percentage of infested trees decreased with time for fipronil treatments only. Significant differences in the percentage of trees infested with native subterranean termites were not observed among insecticide treatments.

Key Words *Coptotermes formosanus*, fipronil, imidacloprid, insecticide foam

INTRODUCTION

An invasive species, the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, is believed to have been introduced in New Orleans and Lake Charles, Louisiana from East Asia around the end of World War II. Its presence was not detected until 1966 (Spink, 1967). This termite is now considered the most destructive insect in Louisiana causing millions of dollars in losses due to treatments, repairs, defaults on loans, and collapse and demolition of structures. It is being spread across Louisiana and to other states. This slow-acting disaster has been described as most important structural pest of the new millennium (Hunter, 2000).

The Louisiana Legislature passed the Formosan subterranean termite initiative on 27 January 1999, which was designed to reduce the densities of Formosan subterranean termites (Louisiana Legislature, 1999). The Louisiana Department of Agriculture and Forestry (LDAF) contracted pest management professionals to treat public trees in the Greater New Orleans and Greater Lake Charles areas. The Louisiana State University (LSU) Agricultural Center conducted a program to evaluate the tree treatment program. Herein, we report on the evaluation of the tree-treating program through 18 months after the trees were treated.

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MATERIALS and METHODS

The tree treatment program was evaluated in Calcasieu (64 trees), Jefferson (25 trees), Orleans (78 trees) and St. Bernard (one tree) parishes, Louisiana beginning in March 2000. Trees were inspected visually on the exterior for the presence of termites before they were treated. Three sites with termites were required for trees to be included in the evaluation. The number of sites with termites on trees were recorded using a grid pattern (on paper) from the ground to 10 feet up the trunk. Termite soldiers were collected each time evaluation trees were inspected and have been stored at the LSU Agricultural Center. Termites were identified as native or Formosan subterranean termites by LSU Agricultural Center personnel. Leaf samples with terminal buds and fruits were collected from each evaluation tree and have been stored at the LSU Agricultural Center. Dr. Diane M. Ferguson, LSU Herbarium, identified tree species. Additional trees were found to be infested but were not included in the evaluation. Soldiers and leaf samples from these trees were collected, identified, and stored in the same manner.

Trees were drilled and treated by pest management professionals under the auspices of LDAF. Zones of variable size in the Greater New Orleans and Greater Lake Charles areas were delineated by LDAF. The same insecticide was used on all public trees (conifers were not treated) within a zone. Trees were treated with imidacloprid (Premise® 0.5 SC, 0.06 kg AI/L) or fipronil (Termidor® SC, 0.12 kg AI/L). Both insecticides were applied at the rate of 15.6 ml/L for the first four months of the program. Rates were increased to 31.3 ml/L (imidacloprid) and 27.3 ml/L (fipronil) thereafter. Four holes 1.27 cm in diameter were drilled in the trunks of trees with diameters greater than 25.4 cm. Holes were drilled at right angles to each other in a clockwise spiral design and moving up the tree 30.5 cm from the previous hole. The first hole was drilled 15.2 cm from the ground on the opposite side of the tree from the street. An additional three holes 1.27 cm in diameter were drilled at right angles to each other 15.2 cm from the ground in trees with diameters 60.9 cm and greater. Insecticide was foamed in trees with a 15 to one (foam to insecticide) expansion ratio. Trees were treated until foam emerged from the openings in the tree with a maximum of five gallons of liquid (75 gallons of foam) applied per tree.

LSU Agricultural Center personnel treated trees with water as control trees following the same procedures used by pest management professionals. Fifteen control trees were established in Sam Houston Jones State Park near Lake Charles, Louisiana, on August 25, 2000. Fifty-two trees treated with fipronil in the greater New Orleans area, fifty-two trees treated with imidacloprid in the greater New Orleans area, forty-nine trees treated with imidacloprid in the greater Lake Charles area, and fifteen trees treated with water in the greater Lake Charles area were evaluated. Trees were visually inspected 1, 6, 12, and 18 months after treatment for active termites. Inspections of water-treated trees at 18 months were not completed at the time of this writing, and these data do not appear in analyses. The number of sites with termites were recorded. Termites were collected, identified, and preserved on each inspection. Formosan subterranean termite foraging above ground is reduced when temperatures fall below 12.8°C (Henderson, unpublished data). Thus, inspections were not conducted when temperatures were below 12.8°C. Some inspections scheduled during time periods of cool temperatures were conducted early to obtain a more accurate measure of termite activity. A boroscope, Vidioprobe® (Everest – VIT, Flanders, New Jersey), was used to make inspections inside trees that were not found to be infested with termites by visual inspection at 12 and 18 months after treatment. Two holes were drilled in such trees and the Vidioprobe® was inserted in the holes.

Data Analysis

Insecticide treatments were assigned to zones in the Greater New Orleans area using a completely randomized design. Trees treated with water were located away from treated areas be-

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cause the tree-treating program attempted to treat all public trees in much of the Greater New Orleans and Greater Lake Charles areas.

Fisher's exact test (one tail) (Steel and Torrie, 1980) was used to compare the percentage of trees infested with Formosan subterranean termites and native subterranean termites before treatment and at 18 months post treatment. The null hypothesis tested was that the percentage of trees infested was equal before treatment and at 18 months post treatment.

Comparisons among treatments were made in the percentage of trees infested with Formosan subterranean termites and native subterranean termites for each sample testing the null hypothesis that the percentages of infested trees among treatments were independent or that equal percentages of trees were infested among treatments. These data were analyzed using a Chi-square test of independence (Steel and Torrie, 1980) (Formosan subterranean termite, New Orleans) or a two-tailed Fisher's exact test (Formosan subterranean termite, Lake Charles and native subterranean termite, New Orleans). Imidacloprid was the only treatment for trees infested with native subterranean termites in the Greater Lake Charles area, and there were no treatments for comparison.

The percentage of Formosan subterranean termite-infested trees observed for each insecticide at each location was compared to the percentage observed for the water treatment using a two-tailed Fisher's exact test for each sample. The null hypothesis tested was that equal percentages of trees were infested in insecticide-treated and water-treated trees. Comparisons between imidacloprid treated trees in the Greater New Orleans and Greater Lake Charles area were made in the percentage of trees infested with Formosan subterranean termites and native subterranean termites for each sample using a two-tailed Fisher's exact test. The null hypothesis tested was that equal percentages of trees were infested in imidacloprid treatments in the Greater New Orleans and Greater Lake Charles areas.

Data from imidacloprid-treated trees were pooled. Comparisons between imidacloprid (data pooled from both locations) and fipronil treatments were made in the percentage of trees infested with Formosan subterranean termites and native subterranean termites for each sample using a two-tailed Fisher's exact test. The null hypothesis tested was that equal percentages of trees were infested in imidacloprid (pooled data) and fipronil treatments.

Data on the number of sites with termites per tree were analyzed using Analysis of Variance and contrasts (Proc GLM, SAS Institute, 1985). Comparisons of treatments were made over locations for each termite on each sample. The null hypothesis of the Analysis of Variance was the mean number of sites with termites was equal in all treatments. Null hypotheses of the contrasts were that the mean number of sites with termites was equal between individual treatment combinations, between all insecticide treatments and water treatments, and both imidacloprid treatments and fipronil treatments.

RESULTS and DISCUSSION

Termites were found infesting 20 families of trees (Tables 1 and 2). Formosan subterranean termites and native subterranean termites were found infesting 16 and 14 families of trees, respectively. Oaks were the most prevalent trees found infested with termites.

Significantly fewer trees were infested with Formosan subterranean termites at 18 months post treatment compared to pretreatment infestations (100 %) in imidacloprid- (Greater New Orleans and Greater Lake Charles areas) and fipronil-treated trees ($P < 0.001$) suggesting that both insecticide treatments reduced the number of infested trees. Significant differences were not observed in the number of trees infested with Formosan subterranean termites at 18 months post treatment compared to pretreatment infestations (100 %) in trees treated with water ($P = 0.5$) suggesting that water treatments failed to reduce infestations of Formosan subterranean termites.

Table 1. Tree species included in the evaluation study and the number of each species infested with Formosan subterranean or native subterranean termites

Family Name	Species Name	Common Name	Formosan	Native
Aceraceae	*Acer rubrum* var. *Drummondii* (Hook. & Arn. Ex Nutt.) Sarg.	Drummond Red Maple	3	4
Cupressaceae	*Juniperus virginiana* L.	Eastern Redcedar	1	-
Euphorbiaceae	*Sapium sebiferum* (L.) Roxb.	Chinese Tallow	2	-
Fagaceae	*Quercus alba* L.	White Oak	1	-
Fagaceae	*Quercus falcata* Michx.	Southern Red Oak	1	-
Fagaceae	*Quercus laurifolia* Michx.	Laurel Oak	5	4
Fagaceae	*Quercus lyrata* Walt.	Overcup Oak	1	-
Fagaceae	*Quercus marilandica* Muench.	Blackjack Oak	-	1
Fagaceae	*Quercus nigra* L.	Water Oak	25	2
Fagaceae	*Quercus pagoda* Raf.	Cherrybark Oak	2	-
Fagaceae	*Quercus phellos* L.	Willow Oak	3	-
Fagaceae	*Quercus shumardii* Buckl.	Shumard's Oak	1	-
Fagaceae	*Quercus texana* Buckl.	Texas Red Oak	2	-
Fagaceae	*Quercus texana* Buckl. / *Quercus shumardii* Buckl. (hybrid)	Texas Red Oak / Shumard's Oak	1	-
Fagaceae	*Quercus virginiana* Mill.	Live Oak	43	13
Hamamelidaceae	*Liquidambar styraciflua* L.	Sweetgum	8	1
Lauraceae	*Cinnamomum camphora* (L.) J. Presl.	Camphor	1	-
Magnoliaceae	*Magnolia grandiflora* L.	Southern Magnolia	3	1
Magnoliaceae	*Liriodendron tulipifera* L.	Tuliptree	-	1
Meliaceae	*Melia azedarach* L.	Chinaberry	1	-
Nyssaceae	*Nyssa sylvatica* Marsh.	Blackgum	1	-
Oleaceae	*Fraxinus pennsylvanica* Marsh.	Green Ash	1	1
Oleaceae	*Fraxinus velutina* Torr.	Velvet Ash	-	1
Platanaceae	*Platanus occidentalis* L.	Sycamore	1	2
Rosaceae	*Pyrus Calleryana* Dcne.	Callery or Bradford Pear	-	1
Salicaceae	*Salix nigra* Marsh.	Black Willow	-	1
Taxodiaceae	*Taxodium distichum* (L.) L.C. Rich	Bald Cypress	5	4
Ulmaceae	*Celtis laevigata* Willd. var. *reticulata* (Torr.) L. Benson	Netleaf Hackberry	5	-
Ulmaceae	*Ulmus americana* L.	American Elm	7	5
Ulmaceae	*Ulmus parvifolia* Jacq.	Chinese Elm	1	-
Ulmaceae	*Ulmus rubra* Muhl	Slippery Elm	-	1

These results indicated that the number of trees infested with Formosan subterranean termites were reduced through the efforts of the tree-treating program.

Significant differences in the percentage of trees infested with Formosan subterranean termites were observed among treatments for all samples in the Greater New Orleans area (Chi-square > 7.1, df = 2, $P < 0.030$) and the Greater Lake Charles area ($P \leq 0.002$) (Table 3). A significantly greater percentage of trees infested with Formosan subterranean were observed in water-treated trees than in fipronil-treated trees ($P \leq 0.014$). A significantly greater percentage of trees infested with Formosan subterranean were observed in water-treated trees than in imidacloprid-treated trees in the Greater Lake Charles area ($P \leq 0.002$) and imidacloprid-treated trees in the Greater New Orleans area at six and 12 months post treatment ($P = 0.040$). However,

Table 2. Additional tree species not included in the evaluation study and the number of each species infested with Formosan subterranean or native subterranean termites

Family Name	Species Name	Common Name	Formosan	Native
Aceraceae	*Acer rubrum* var. *Drummondii* (Hook. & Arn. Ex Nutt.) Sarg.	Drummond Red Maple	7	2
Aceraceae	*Sabal* Adans.	Palmetto	-	1
Betulaceae	*Betula nigra* L.	River Birch	-	1
Euphorbiaceae	*Sapium sebiferum* (L.) Roxb.	Chinese Tallow	1	
Fagaceae	*Quercus virginiana* Mill.	Live Oak	10	1
Fagaceae	*Quercus nigra* L.	Water Oak	5	-
Fagaceae	*Quercus laurifolia* Michx.	Laurel Oak	6	-
Fagaceae	*Quercus texana* Buckl.	Texas Red Oak	8	-
Fagaceae	*Quercus phellos* L.	Willow Oak	1	-
Fagaceae	*Quercus alba* L.	White Oak	2	-
Fagaceae	*Quercus shumardii* Buckl.	Shumard's Oak	2	-
Fagaceae	*Quercus texana* Buckl. / *Quercus shumardii* Buckl. (hybrid)	Texas Red Oak / Shumard's Oak	1	-
Fagaceae	*Quercus ?*	Dead Oak	1	-
Hamamelidaceae	*Liquidambar styraciflua* L.	Sweetgum	2	-
Juglandaceae	*Carya illinoinensis* (Wangenh.) K. Koch.	Pecan	1	-
Leguminosae	*Cercis canadensis* L.	Redbud		1
Magnoliaceae	*Magnolia grandiflora* L.	Southern Magnolia	1	1
Moraceae	*Morus rubra* L.	Red Mulberry	-	1
Oleaceae	*Fraxinus pennsylvanica* Marsh.	Green Ash	3	-
Pinaceae	*Pinus taeda* L.	Loblolly Pine	-	2
Pinaceae	*Pinus elliottii* Engelm.	Slash Pine	2	2
Platanaceae	*Platanus occidentalis* L.	Sycamore	-	1
Salicaceae	*Salix nigra* Marsh.	Black Willow	1	-
Taxodiaceae	*Taxodium distichum* (L.) L.C. Rich	Bald Cypress	4	-
Ulmaceae	*Ulmus americana* L.	American Elm	10	-
Ulmaceae	*Celtis laevigata* Willd. var. *reticulata* (Torr.) L. Benson	Netleaf Hackberry	1	-
Ulmaceae	*Ulmus rubra* Muhl.	Slippery Elm	1	-

significant differences in the number of Formosan subterranean termite-infested trees were not observed between water-treated trees and imidacloprid-treated trees in the Greater New Orleans area at one and 18 months post treatment ($P > 0.070$). These results indicate that the percentage of trees infested with Formosan subterranean termites were reduced in the fipronil and imidacloprid treatments.

A significantly lower percentage of trees infested with Formosan subterranean termites was observed in imidacloprid-treated trees in the Greater Lake Charles area than in the Greater New Orleans area at one and 18 months post treatment ($P \leq 0.037$) (Table 3). However, significant differences in the percentage of Formosan subterranean termite-infested trees was not observed in imidacloprid-treated trees in the Greater Lake Charles and the Greater New Orleans area at six and 12 months post treatment ($P > 0.060$). Significant differences in the percentage of Formosan subterranean termite-infested trees were not observed in imidacloprid (pooled data) treatments and fipronil treatments at 1, 6, and 18 months post treatment ($P \geq 0.069$). However, a significantly

Table 3. Percentage of evaluation trees infested with Formosan subterranean termites in imidacloprid, fipronil, and water treatments in the Greater New Orleans and Greater Lake Charles areas at 1, 6, 12, and 18 months after treatment[a]

Treatment, Location	1 Month	6 Months	12 Months	18 Months
imidacloprid, N. O.	67 (33)	55 (33)	64 (33)	66 (32)
fipronil, N. O.	49 (39)	44 (25)	32 (38)	32 (38)
imidacloprid, L. C.	40 (40)	34 (29)	45 (40)	40 (40)
Water, L. C.	87 (15)	93 (15)	93 (15)	N/A

[a]N. O., New Orleans; L. C., Lake Charles; number in parenthesis is the total number of trees evaluated; N/A, treatments not in place for 18 months.

lower percentage of Formosan subterranean termite infested trees was observed in fipronil treatments than in imidacloprid (pooled data) treatments at 12 months post treatment ($P = 0.044$).

Significantly fewer trees were infested with native subterranean termites at 18 months post treatment compared to pretreatment infestations (100 %) in imidacloprid- (Greater New Orleans and Greater Lake Charles areas) and fipronil-treated trees ($P \leq 0.041$), suggesting that both insecticide treatments reduced the number of trees infested with native subterranean termites. Treatments were applied to the inside of trees. Native subterranean termites are not known to infest the centers of living trees but tunnel up the outside. The observed reduction may have been due to native subterranean termites abandoning trees after disturbance, a conclusion supported by an increase in the percentage of trees infested with native subterranean termites with increased time after treatment in imidacloprid treatments. However, the percentage of trees infested with native subterranean termites has remained around 30 % after one month post treatment (Table 4).

Significant differences in the percentage of trees infested with native subterranean termites were not observed among treatments for all samples in the Greater New Orleans area ($P \geq 0.171$). Significant differences in the percentage of trees infested with native subterranean termites were not observed in imidacloprid-treated trees in the Greater Lake Charles and the Greater New Orleans area for all samples ($P > 0.425$) and in comparisons of imidacloprid (pooled data) treatments to fipronil treatments for all samples ($P \geq 0.119$) (Table 4). These results indicate that insecticide treatments impacted native subterranean termites equally.

Significant differences in the mean number of sites with Formosan subterranean termites were observed among treatments on each sample (one month, $F = 5.13$, df = 3, 121, $P > F = 0.002$; six months, $F = 5.30$, df = 3, 121, $P > F < 0.002$; 12 months, $F = 6.84$, df = 3, 121, $P > F < 0.001$; 18 months, $F = 6.26$, df = 2, 107, $P > F = 0.003$) (Table 5). Treatments ranked from lowest to highest number of sites with Formosan subterranean termites were fipronil, imidacloprid in the Greater Lake Charles area, water, and imidacloprid in the Greater Lake Charles area.

Table 4. Percentage of evaluation trees infested with native subterranean termites in imidacloprid, and fipronil treatments in the Greater New Orleans and Greater Lake Charles areas at 1, 6, 12, and 18 months after treatment[a]

Treatment, Location	1 Month	6 Months	12 Months	18 Months
imidacloprid, N. O.	30 (20)	50 (20)	45 (20)	55 (20)
fipronil, N. O.	50 (14)	27 (11)	29 (14)	29 (14)
imidacloprid, L. C.	33 (9)	0 (5)	67 (9)	56 (9)

[a]N. O., New Orleans; L. C., Lake Charles; number in parenthesis is the total number of trees evaluated.

Proceedings of the 4th International Conference on Urban Pests.
Susan C. Jones, Jing Zhai, and Wm H. Robinson editors. (2002)

Table 5. Number of sites per tree with Formosan subterranean termites in imidacloprid, fipronil, and water treatments in the Greater New Orleans and Greater Lake Charles areas at 1, 6, 12, and 18 months after treatment[a]

Treatment, Location	1 Month	6 Months	12 Months	18 Months
fipronil, N. O.	1.7 (38)	1.1 (24)	0.9 (38)	0.9 (38)
imidacloprid, L. C.	1.3 (40)	1.4 (29)	1.6 (40)	1.2 (40)
Water, L. C.	2.3 (15)	3.3 (15)	2.6 (15)	N/A

[a]N. O., New Orleans; L. C., Lake Charles; number in parenthesis is the total number of trees evaluated; N/A, treatments not in place for 18 months.

Significant differences in the mean number of sites with Formosan subterranean termites were not observed between insecticide treatments and the water treatment at one and 12 months post treatment ($P > F > 0.763$, contrast of all insecticide treatments versus water; $P > F > 0.114$, contrasts of individual insecticide treatments versus water) but were observed at six months post treatment ($P > F = 0.013$, contrast of all insecticide treatments versus water; $P > F < 0.048$, contrast of individual insecticide treatments versus water) (Table 5). Significant differences in the mean number of sites with Formosan subterranean termites were not observed between fipronil treatments and imidacloprid treatments in the Greater Lake Charles area at 6,12, and 18 months post treatment ($P > F > 0.424$) but were observed at one month post treatment ($P > F = 0.023$). However significant differences in the mean number of sites with Formosan subterranean termites were observed between fipronil and imidacloprid in the Greater New Orleans area on all samples ($P > F < 0.007$). Significantly fewer sites with active Formosan subterranean termites were observed on imidacloprid-treated trees in the Greater Lake Charles area than the Greater New Orleans area on all samples ($P > F < 0.014$). These results indicated that fipronil and imidacloprid in the Greater Lake Charles area reduced the number of sites with Formosan subterranean termites compared to imidacloprid in the Greater New Orleans area.

Significant differences in the mean number of sites with native subterranean termites were not observed among treatments (one month, $F = 0.60$, df = 2, 40, $P > F = 0.551$; six months, $F = 1.85$, df = 2, 40, $P > F = 0.170$; 12 months, $F = 0.17$, df = 2, 40, $P > F = 0.841$; 18 months, $F = 0.99$, df = 2, 40, $P > F = 0.379$) (Table 6). Similarly, significant differences were not detected in the mean number of sites with native subterranean termites on any sample using contrasts between fipronil and imidacloprid in the Greater Lake Charles area ($P > F > 0.763$), fipronil and imidacloprid in the Greater New Orleans area ($P > F > 0.120$), and imidacloprid in the Greater Lake Charles area and in the Greater New Orleans area ($P > F > 0.121$).

The treatment of trees may be an important part of area-wide management programs for the Formosan subterranean termite such as the French Quarter Program (Ring et al., 2000). Nonrepellent insecticides such as those used in this program will have the potential to impact termite

Table 6. Number of sites per tree with native subterranean termites in imidacloprid and fipronil treatments in the Greater New Orleans and Greater Lake Charles areas at 1, 6, 12, and 18 months after treatment[a]

Treatment, Location	1 Month	6 Months	12 Months	18 Months
imidacloprid, N. O.	0.8 (20)	2.2 (20)	1.5 (20)	2.0 (20)
fipronil, N. O.	1.5 (14)	0.6 (14)	1.4 (14)	0.9 (14)
imidacloprid, L. C.	1.6 (9)	0.3 (9)	1.3 (9)	1.2 (9)

[a]N. O., New Orleans; L. C., Lake Charles; number in parenthesis is the total number of trees evaluated.

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survival away from the treatment area. There will be a continuous need to manage Formosan subterranean termites in trees to protect trees and nearby structures.

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